United States Patent [19]

Bilanin

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[45] **Date of Patent: Jul. 28, 1987**

[54] **VEHICLE DRAG REDUCER**

[76] Inventor: **Alan J. Bilanin**, 62 Battle Rd., Princeton, N.J. 08540

[21] Appl. No.: **758,405**

[22] Filed: **Jul. 24, 1985**

[51] **Int. Cl.⁴** **B62D 35/00**

[52] **U.S. Cl.** .... **296/1 S**; 296/91

[58] **Field of Search** .... 296/1 S, 91; 105/2 R

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Primary Examiner—Robert B. Reeves
Assistant Examiner—Russell D. Stormer
Attorney, Agent, or Firm—Richard C. Woodbridge

[57] **ABSTRACT**

A drag reducing apparatus is attached to the back of a vehicle and serves to reduce drag by capturing at least two vortices which turn the flow inwardly behind the vehicle body thereby effectively reducing the back area of the vehicle. The first and second vortices are captured in cavities formed by a first and a second vertical panel attached to the back of a vehicle. A third horizontal panel can be attached to the top of the first and second panels to create a cavity for the capture of a third vortex formed by the air stream flowing over the top of the vehicle. The panels are preferably hinged so that they can be folded up flat against the rear of the vehicle when not in use. When in use the panels are locked in position so that they don't vibrate when the vehicle is moving. Top and bottom panels can be employed to define the upper and lower limits of the first and second vortex. Other embodiments employ different panel arrangements to improve the efficiency of the vortex capture.

16 Claims, 24 Drawing Figures

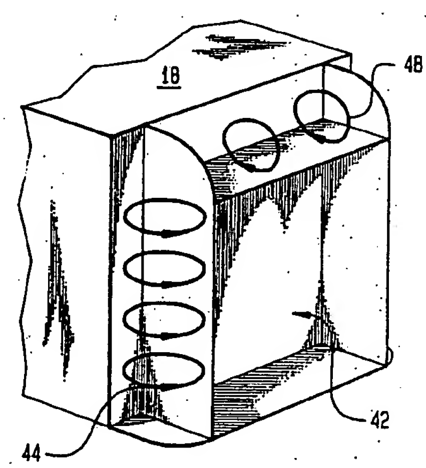


FIG. 1A
(PRIOR ART)

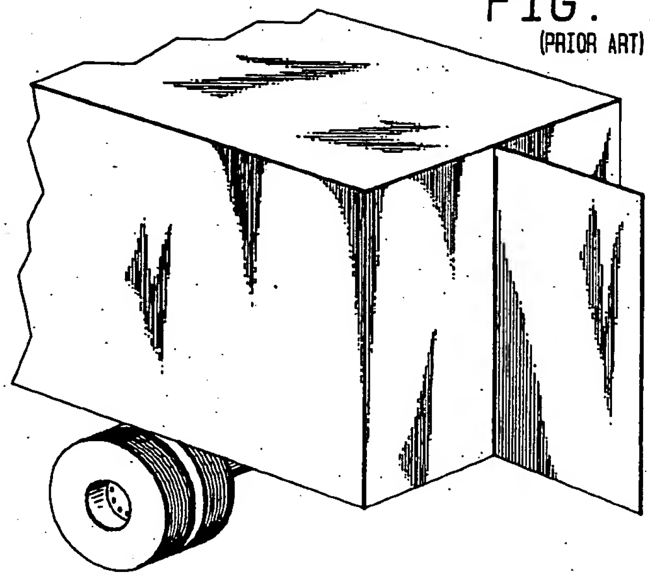


FIG. 1B
(PRIOR ART)

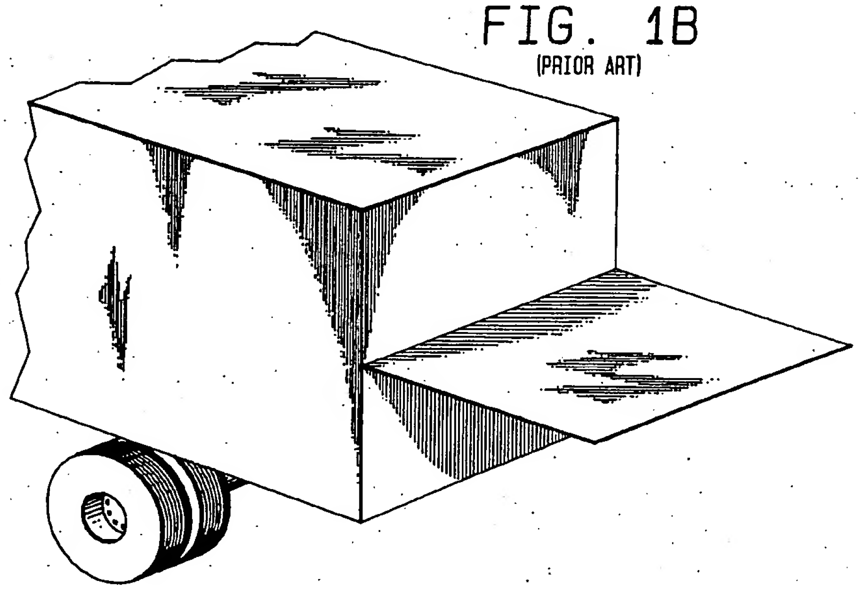


FIG. 1C
(PRIOR ART)

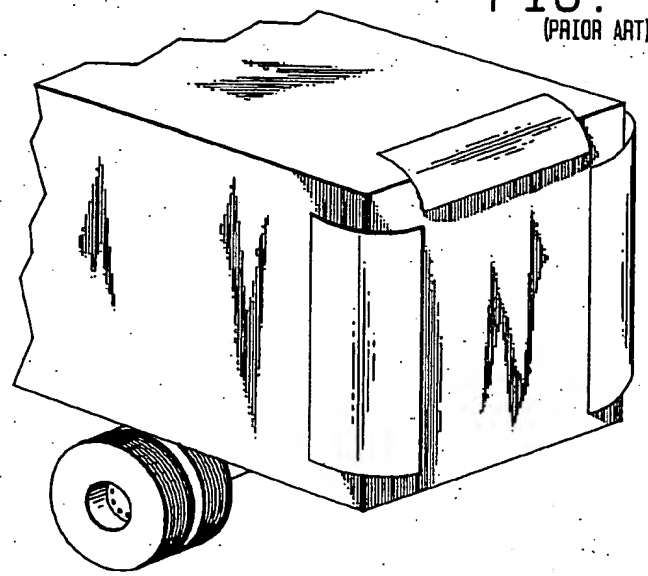


FIG. 1D
(PRIOR ART)

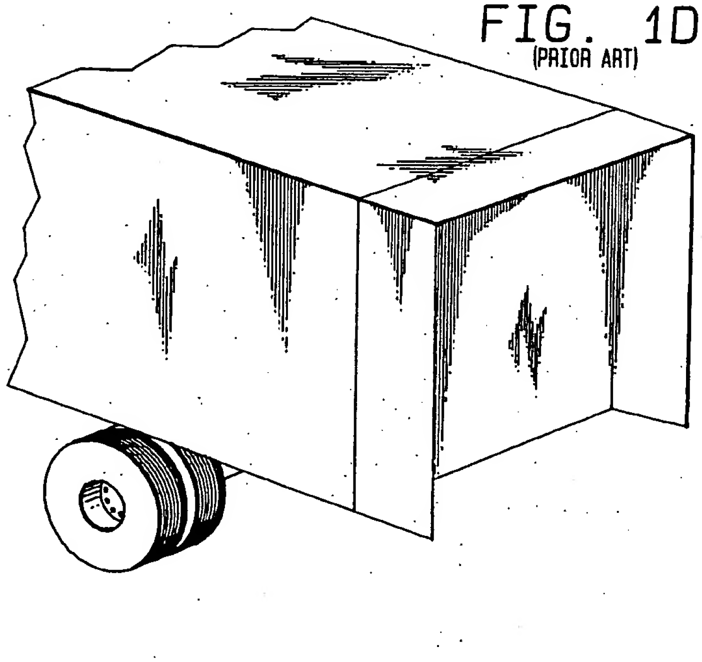


FIG. 1F
(PRIOR ART)

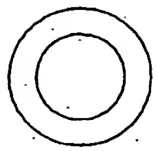


FIG. 1E
(PRIOR ART)

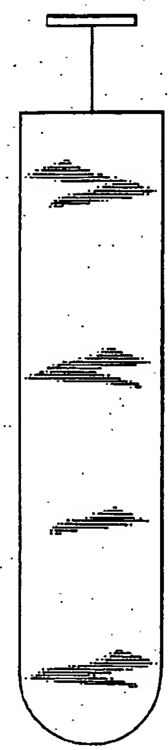


FIG. 1G
(PRIOR ART)

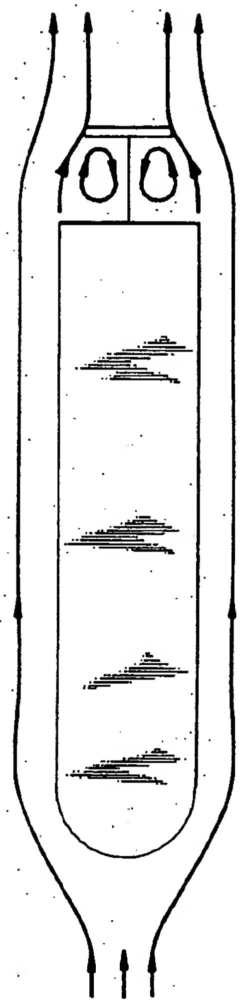


FIG. 2A

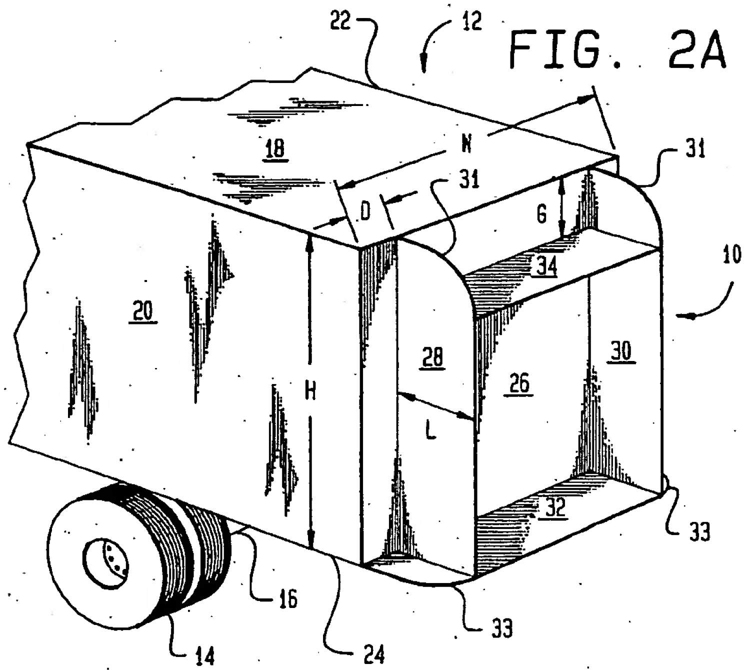


FIG. 2B

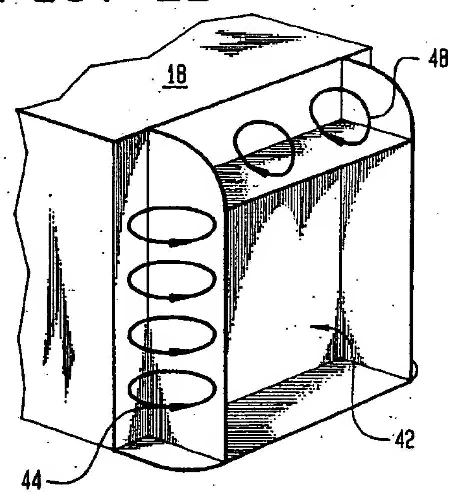


FIG. 2D

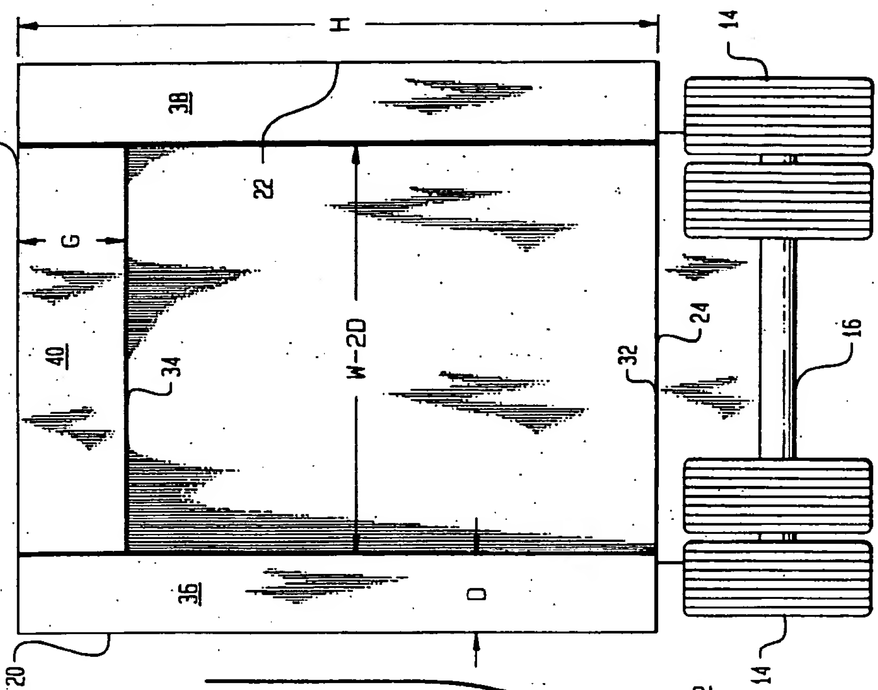

H
18
38
22
G
40
34
W-2D
32
24
14
16
36
D
20
14

FIG. 2C

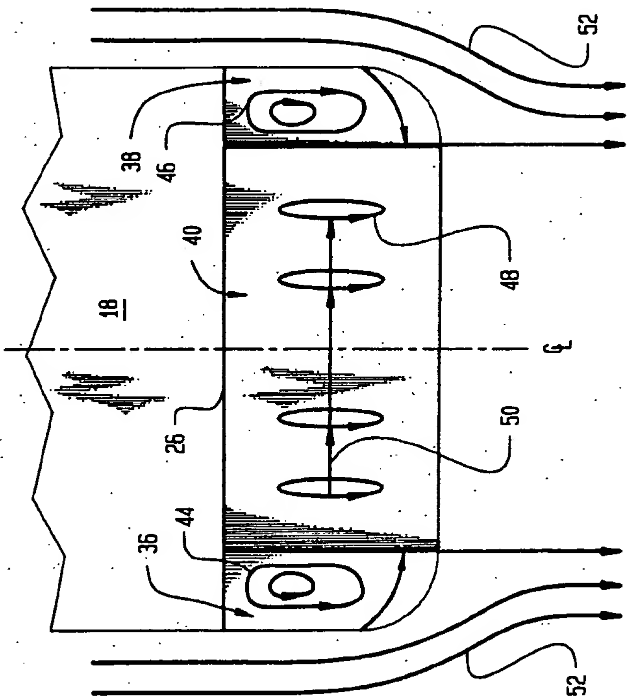

52
38
46
40
48
18
26
50
44
36
52

FIG. 2F

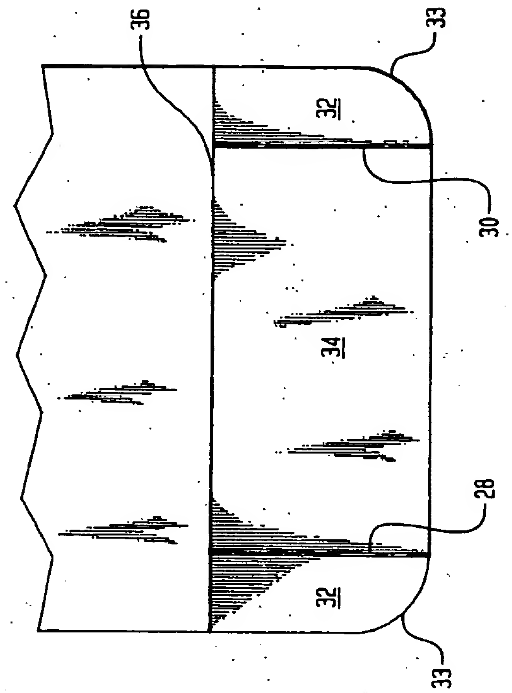
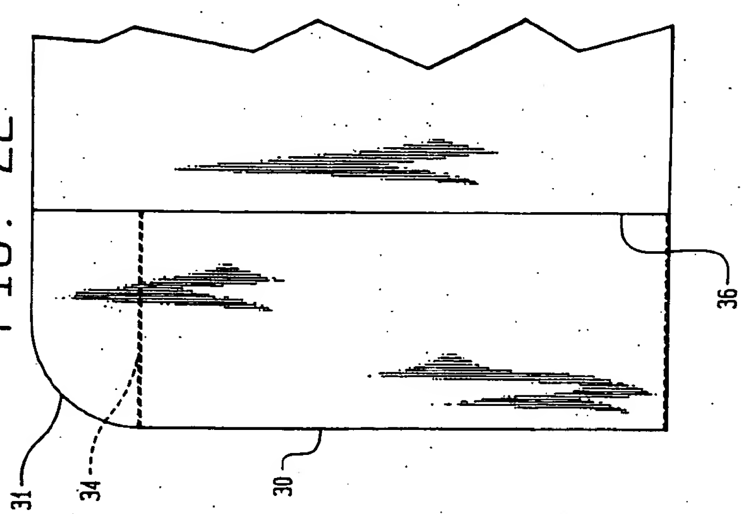


FIG. 2E



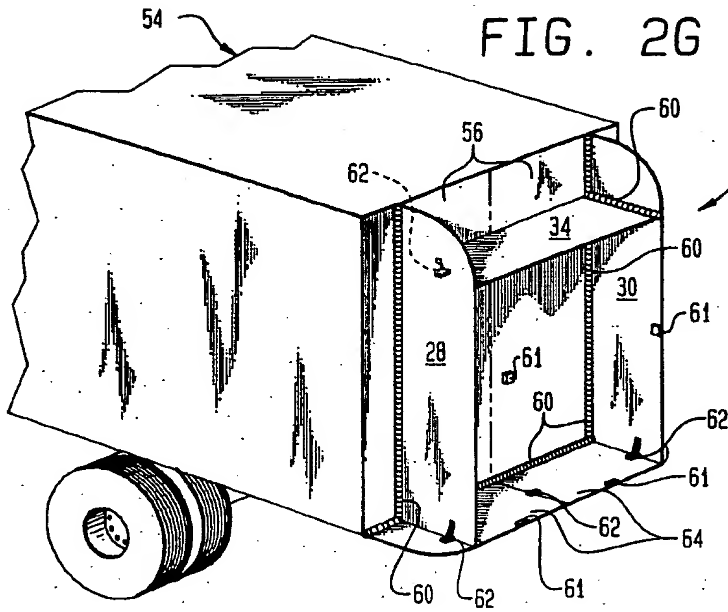


FIG. 2G

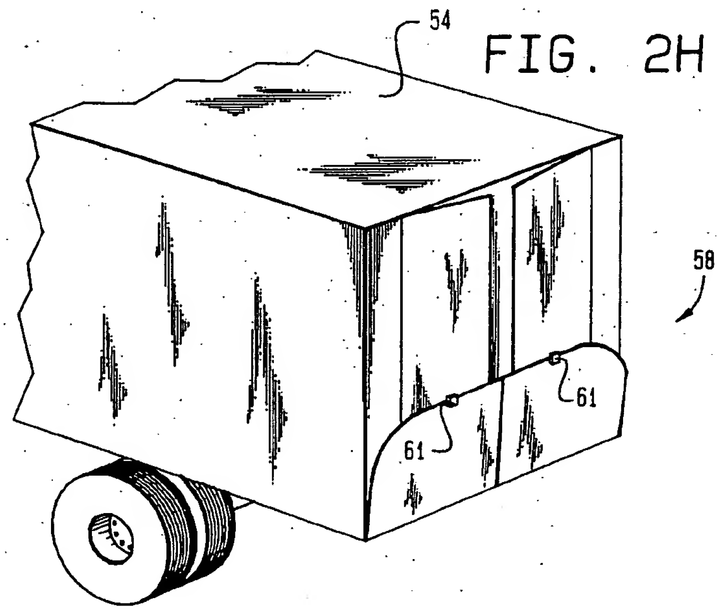


FIG. 2H

FIG. 2I

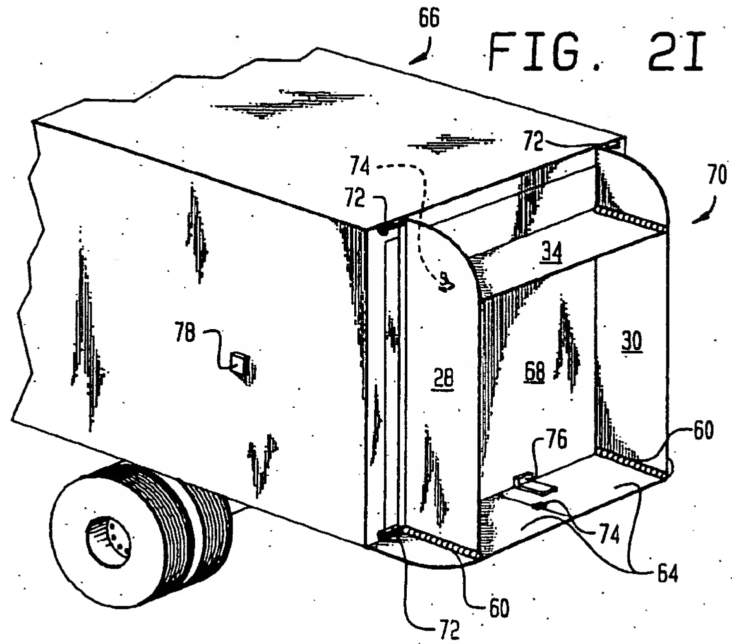


FIG. 3

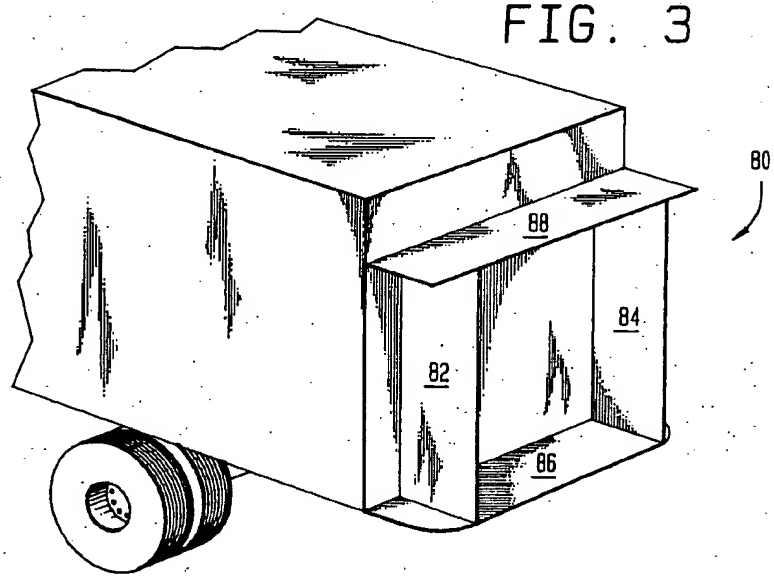


FIG. 4

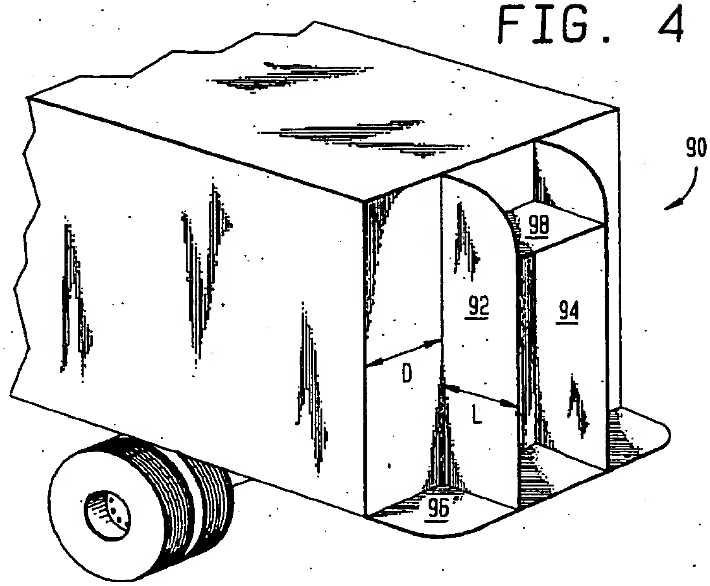


FIG. 5

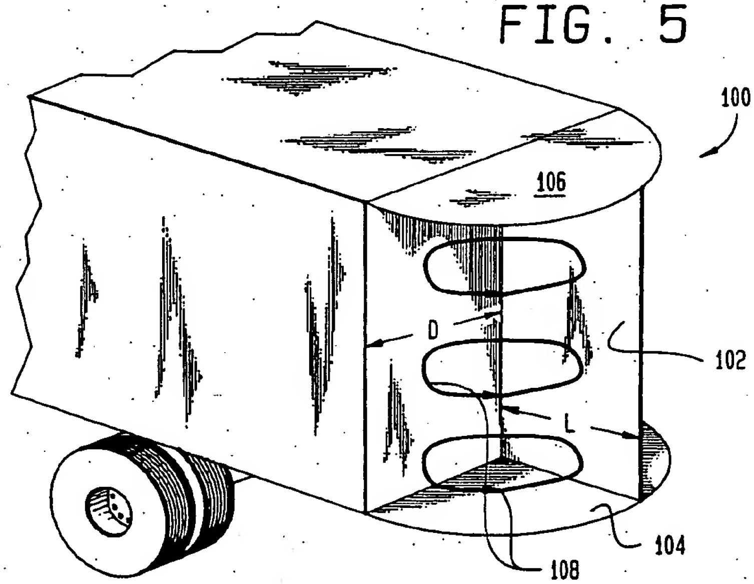


FIG. 6

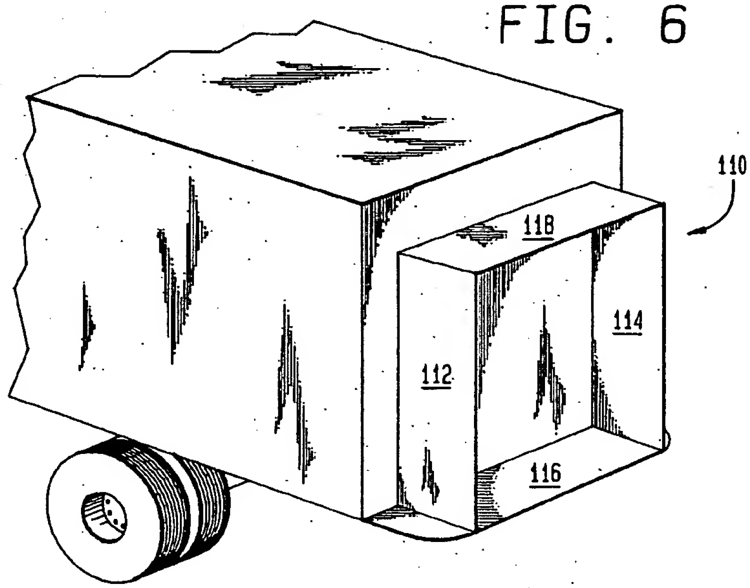


FIG. 7

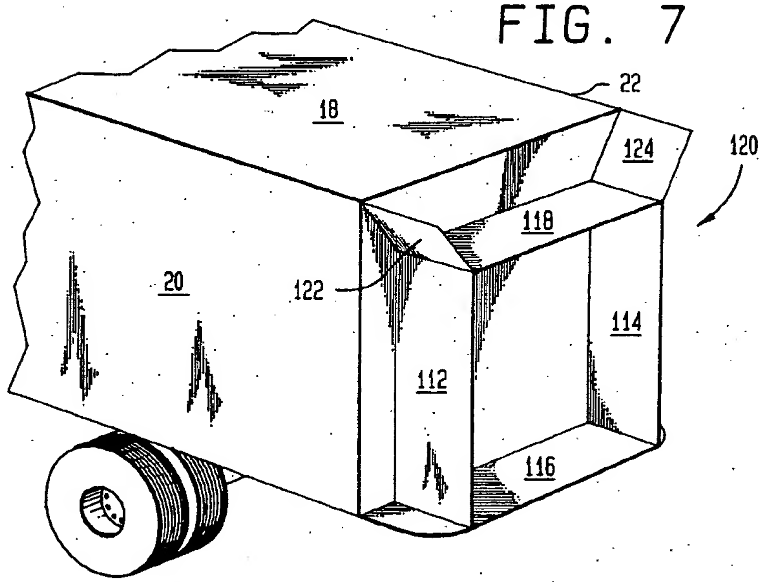


FIG. 8

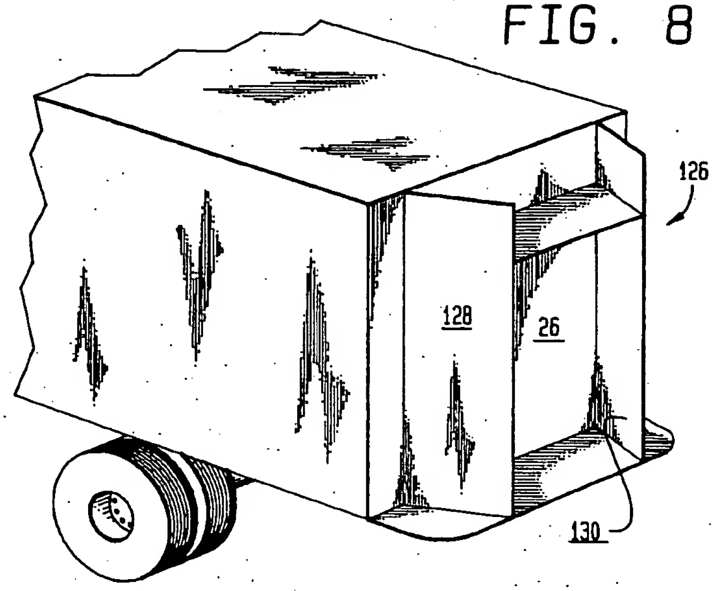


FIG. 9

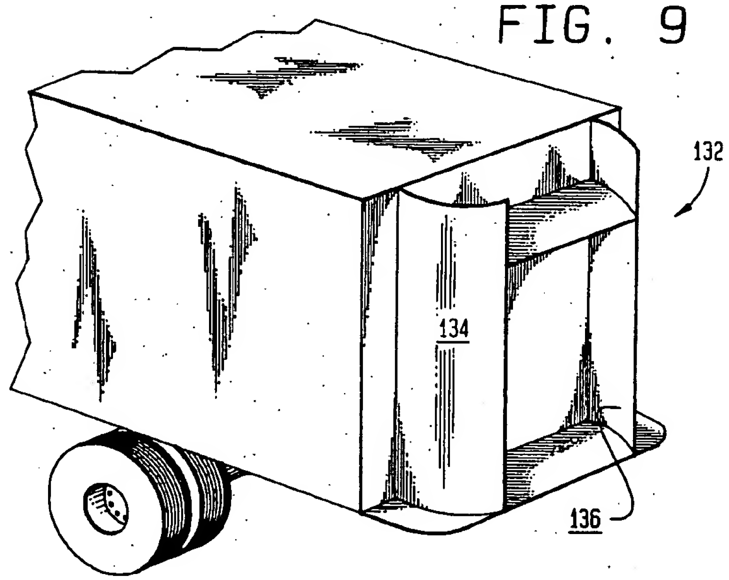
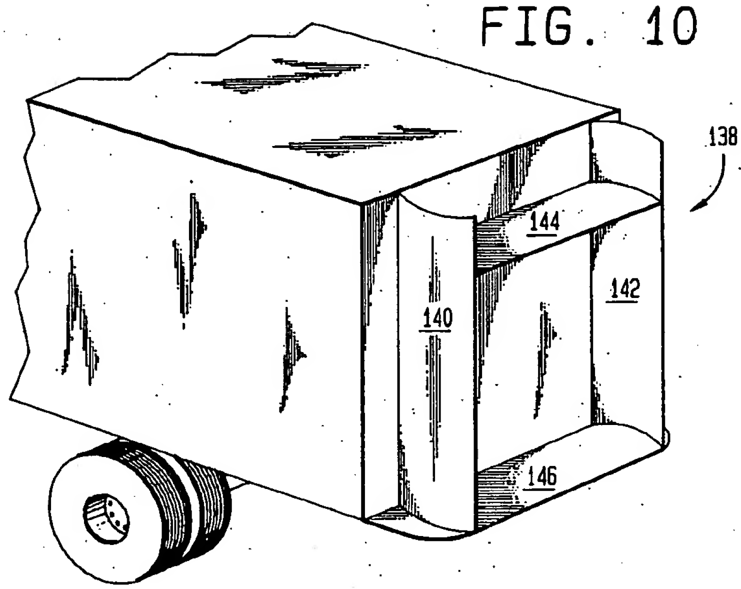


FIG. 10



VEHICLE DRAG REDUCER

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention comprises an apparatus attached to the back of a vehicle for reducing the fluid drag thereon by creating at least two vortices which turn the flow inwardly after it passes the sides of the body.

2. Description of the Prior Art

A number of efforts have been made to reduce the aerodynamic drag on blunt bodies such as semi-trailers and trailer vans. In general vans have a blunt rear end in order to improve ease of fabrication of rear loading doors and also so that the trailer can butt directly against loading docks. Blunt ended moving bodies have high drag as a consequence of relatively lower pressures acting on the rear base of the vehicle. The base pressure results in base drag and the reduction of this drag has received some attention by previous investigators and inventors. Boat tailing, which involves adding a tapered extension backward from the blunt base, has long been known to reduce base drag. However, those devices are bulky and must be removed to permit loading of the truck. U.S. Pat. No. 4,257,641 entitled VEHICLE DRAG REDUCER discloses a boat tail which replaces the conventional system of doors. Similarly, U.S. Pat. No. 4,451,074 describes a collapsible boat tailing airfoil in which the airfoils can be folded away from the base and against the side of the trailer when the vehicle is backed into a loading dock. Unfortunately boat tails are relatively large structures and require the substantial deployment of hardware. As a compromise the boat tail may be reduced in size by not tapering the end to a point such as described in U.S. Pat. No. 4,214,787 entitled DRAG REDUCING APPARATUS. Such a device could be referred to as a partial boat tail. Alternatively, Freuhauf produced an experimental FEV 2000 tractor semi-van trailer vehicle which was built in 1981. An interesting description of the FEV 2000 vehicle is found in an article entitled "The Truck of the Future" which appeared in the June 1985 edition of High Technology Magazine on pages 28 through 33. However, base drag reduction using partial boat tailing is not as great as that achieved when using full boat tailing. This performance degradation may be somewhat offset by using a vortex generator on the partial boat tail such as described in U.S. Pat. Nos. 3,741,285 and 3,776,363. Other devices described in the patent literature but not believed to be as relevant to the present invention are described in U.S. Pat. Nos. 2,514,695; 3,934,923; 3,960,402; 3,971,586; 3,999,797; 4,113,299; 4,316,360 and 4,451,074.

Another approach to reducing base drag is to bleed air into the base area. Studies undertaken by Sykes, in the 1969 Proceedings of the First Symposium on Road Vehicle Aerodynamics at the City University in London, have shown that significant reductions in base drag can be achieved. Unfortunately, when estimates are made of the power required to supply the air to the base region, the concept becomes impractical and uneconomical.

Another alternative method to reduce base drag was proposed by W. T. Mason, Jr. and P. S. Beebee, in the Proceedings of the Symposium on Aerodynamic Drag Mechanisms of Bluff Bodies and Road Vehicles, sponsored by General Motors Research Laboratories on Sept. 27-28, 1976. The concept was to install a single splitter plate either vertically or horizontally extending perpendicular off the rear base of the truck. The purpose of the plate was to allow the flow separating from the side of the truck to reattach to the vertical plate or the flow separating from the roof and the bottom of the truck to reattach to the horizontal plate. Unfortunately, very little reduction in base drag was achieved with that concept.

Four of the embodiments studied by Mason and Beebee are illustrated in FIGS. 1A through 1D and labeled as "Prior Art." FIG. 1A illustrates a single vertical splitter. Unfortunately, to be effective a single vertical splitter has to extend an unreasonably long distance behind a van. Moreover, the inherent instability of the vortices created on both sides of the single splitter causes the resultant drag reduction to be relatively poor. FIG. 1B is similar to FIG. 1A except that the single splitter is located in the horizontal plane. This technique was also believed to be ineffective due to the extreme length of the single splitter and the turbulence generated beneath the truck carriage. FIG. 1C illustrates another prior art technique in which turning vanes are used to turn the airflow around the sides inwardly thereby reducing the effective base drag area of the van. FIG. 1D illustrates another prior art technique examined by Maso and Beebee in which a dead air space cavity was effectively formed behind the end of a semi-trailer van by extending the plane on the side and top surfaces of the vehicle. In general the results obtained by the prior art techniques 1A through 1D were disappointing, especially when viewed in light of the results obtained by the present invention.

The splitter plate concept has been shown to be effective in reducing the base drag of two-dimensional bodies such as the blunt trailing edge of an airplane wing. See for example, M. Tanner, Progress in Aerospace Science, Vol. 16, No. 4, pp. 369-384, Pergamon Press, 1975. Apparently the flow behind a truck is more complicated than a flow behind a simple two-dimensional body. Another approach using plates to reduce base drag is to attach plates so that they are flush to either the sides or the roof or the floor of a vehicle and then extended backwards. In an experiment reported by D. J. Maull, in the Proceedings of the Symposium on Aerodynamic Drag Mechanisms of Bluff Bodies and Road Vehicles, sponsored by General Motors Reseach Laboratories in 1978, such plates provided relatively modest but not sufficient reduction in base drag to be economically viable.

An article entitled The Effect of a Rear-Mounted Disc on the Drag of a Blunt-Based Body of Revolution, by W. A. Mair, and published in The Aeronautical Quarterly, Nov. 1965 has shown that a disc of revolution mounted on a base of revolution can reduce base drag substantially. Such a device is shown in FIGS. 1E, 1F and 1G and is labeled "Prior Art". The reduction in drag is believed to be the result of a vortex ring eddy trapped between the base of the body and the disc as shown in FIG. 1G. The vortex ring is believed to help turn the flow inward downstream of the base and, hence, reduce the effective base area of the body of revolution. Unfortunately, a simple rectangular plate cannot be attached to the base of a truck with similar success, since the axis of a vortex ring cannot be bent to a rectangular configuration to conform to the space between the base and the rectangular plate. The Mair concept does, however, describe the use of trapped vortices to reduce the base drag of vehicles.

The disappointing results of the prior art suggest that no one, to date, has successfully trapped a vortex behind a body similar to a semi-trailer or trailer van. The present invention appears to have been successful in efficiently trapping a vortices and obtaining drag reduction in the neighborhood of 10.2%. This has resulted in substantial drag reduction all of which could have a significant impact on the cost of trucking and our quality of life. In the United States semi-trailer vans expend over 10 billion gallons of diesel fuel per year. A needless waste of fuel increases dependency on imported oil, as well as adding needless diesel exhaust carcinogens into the atmosphere. It had previously been difficult to reduce the drag on blunt bodies by trailing devices given federal and state regulations. However, recently the United States Congress has enacted legislation which permits trailer/semi-trailer length limits to be exceeded if the purpose is to improve fuel efficiency. It appears that the present invention can reduce the aerodynamic drag of a semi-trailer or trailer van in excess of 10%. This could result in a nationwide yearly savings of diesel fuel in excess of 1 billion gallons.

SUMMARY OF THE INVENTION

Briefly described the invention comprises a device attached to the back end of a vehicle for capturing two drag reducing vortices. The vehicle could be any vehicle that has a relatively blunt back end including but not limited to trailer and semi-trailer vans, buses and trucks. According to the simplest embodiment, the invention comprises a vertical panel and a horizontal panel which form two cavities for capturing two vortices. The horizontal panel may be on top of or below the vertical panel and the vertical panel is located half way between the left and right sidewalls of the vehicle. The preferred embodiment comprises two vertical panels which form cavities for respectively capturing the first and second vortices. A third panel which is horizontal with respect to the top surface of the vehicle and perpendicular with respect to the first and second panels, serves to define a third cavity to capture a third vortex having an axis of rotation perpendicular to the axis of rotation of the first and second captured vortices. Additional panels can be added to further improve the efficiency of the vortex capturing scheme just described. The invention is preferrably employed in the context of a semi-trailer or trailer van having a height H and a width W. According to the preferred embodiment the vertical panel or panels are located a distance D from the edge of either sidewall such that the ratio D/W is less than ¼. According to alternative embodiments of the invention additional paneling may be added to further stabilize and define the capture of the vortices. These and other features of the invention will be more fully understood by reference to the following drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a prior art embodiment employing a single vertical splitter.

FIG. 1B is a prior art embodiment employing a single horizontal splitter.

FIG. 1C is a prior art embodiment employing three turning vanes.

FIG. 1D is a prior art embodiment in which a single large cavity is formed at the rear of the semitrailer.

FIG. 1E is a side view of a prior art embodiment for capturing a vortex behind a blunt-based body of revolution.

FIG. 1F is an end view of the prior art embodiment of FIG. 1E.

FIG. 1G is a schematic view of the prior art embodiment of FIG. 1E showing the manner in which captive vortex eddy rings are believed to be contained between the rear of the body of revolution and a trailing disc.

FIG. 2A is a perspective view of the preferred embodiment of the present invention.

FIG. 2B is a detail perspective view of the preferred embodiment of FIG. 2A showing the manner in which vortices are captured in order to assist in drag reduction.

FIG. 2C is a top plan view of the preferred embodiment of FIG. 2A showing the manner in which the vortices are captured.

FIG. 2D is a rear elevational view of the preferred embodiment of FIG. 2A.

FIG. 2E is a partial right side elevational view of the preferred embodiment of FIG. 2A.

FIG. 2F is a partial top plan view of the preferred embodiment of FIG. 2A.

FIG. 2G is a perspective view of the preferred embodiment shown in FIG. 2A but modified so that it can be attached to a semi-trailer van having two flat rear swing doors.

FIG. 2H is a perspective view of the modified version of the preferred embodiment shown in FIG. 2G illustrating the manner in which the two rear doors and the drag reducer can be collapsed and locked against the sides and rear of the semi-trailer van body.

FIG. 2I is a perspective view of the preferred embodiment of FIG. 2A, but modified to fit on the back of a semi-trailer van having roll-up doors.

FIG. 3 is a perspective view of an alternative embodiment of the present invention.

FIG. 4 is a perspective view of another alternative embodiment of the present invention.

FIG. 5 is a perspective view of a limiting alternative embodiment of the present invention including the captured vortices.

FIG. 6 is a perspective view of yet another embodiment of the present invention.

FIG. 7 is a perspective view of a modification of the altervative embodiment of the present invention illustrated in FIG. 6.

FIG. 8 is a perspective view of a variation of the preferred embodiment illustrated in FIG. 2A in which the vertical splitter panels are turned inwardly.

FIG. 9 is a perspective view of another modification of the preferred embodiment as illustrated in FIG. 2A in which the vertical splitter panels are curved inwardly.

FIG. 10 is a perspective view of another modification of the preferred embodiment illustrated in FIG. 2A in which the vertical splitter panels and the top and bottom horizontal panels are all curved in order to direct flow.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

During the course of this description like numbers will he used to identify like elements according to the different figures which describe the invention.

In general the invention comprises an apparatus for reducing the base drag behind bluntly ended or truncated vehicles by affixing two or more panels to the base of the vehicle. The vehicle could be any vehicle having a relatively blunt back end including trailer and semi-trailer vans, buses, minivans, minibuses, recre-

ational vehicles, trucks, etc. The panels permit trapped or captured eddys to be stabilized and generated. The stabilized vortices turn the flow along the roof, sides and bottom of the vehicle inwardly towards the center line of the rear of the vehicle. The vortices aerodynamically close the base flow after the vehicle so that the flow field is similar to that about a boat tail. The base pressure is raised by the pressure recovery which occurs as the result of turning the flow inward toward the center line of the base.

The preferred embodiment 10 of the present invention is illustrated in the perspective view of FIG. 2A. The drag reducing invention 10 is attached to the rear 26 of a conventional van 12. The front end of the van 12 is not illustrated since it is conventional and forms no part of the invention. The van 12 however could be the rear end of a van, the rear end of a trailer or semi-trailer, the rear end of a bus, or the rear end of a standard truck. Those vehicles all share the common characteristic of being blunt bodies having a relatively flat trailing rear section 26. The trailing section of the van 12 is supported by wheels 14 connected by a standard axle 16. The presence of wheels 14 and axle 16 tends to increase the turbulence generated underneath the van which is generally more severe than the turbulence coming from the sides and top of the van.

Each prior art van includes the following conventional points of reference: a top side 18; a left side 20; a right side 22; a bottom side 24 and, as previously discussed, a rear section 26. The rear section may include two flat hinged swing rear doors 56 such as illustrated in FIG. 2G or may include a roll-up rear door arrangement 68 such as illustrated in FIG. 2I.

As shown in FIG. 2A, two vertical panels are attached to the rear 26 of van 12 a distance D away from the left side 20 and the right side 22. A bottom panel 32 extends the plane of the bottom portion 24 of the van 12 rearwardly by distance L. Similarly a top panel 34 located a distance G from the top 18 of the van 12 extends rearwardly by the same distance L and spans the space between the two vertical panels 28 and 30. Accordingly, the length of top panel 34 is the width W of the top surface 18 minus twice the offset D of vertical panels 28 and 30, i.e. length of panel 34=W−2D. Vertical panels 28 and 30 have a height H equal to the height of the sides of the van 20 and 22 and both panels extend rearwardly by the distance of L so that all panels 28, 30, 32 and 34 all extend rearwardly by the same distance L. While the preferred embodiment has panels that all extend backward by the same distance, it would also be possible to operate with panels of different rearward extensions L. The top portions 31 of vertical panels 28 and 30 are curved downwardly whereas the bottom portions of panels 28 and 30 are cut off square with respect to the surface of bottom panel 32.

Vertical panels 28 and 30 along with bottom panel 32 and the van base 26 form two, three-sided cavities 36 and 38 respectively which permit a first vortex 44 and a second vortex 46 to be stabilized or trapped inside of those cavities. The nature of the vortex capturing mechanism is best understood by referring to FIGS. 2B and 2C. Side vortex cavities 36 and 38 formed by panels 28, 30 and 32 and van base 26 have a high aspect ratio. This means that D/H and L/H are less than unity in order to trap a stable vortex. A D/H less than unity permits the flow from the sides of the van to reattach to either vertical panel 28 or 30. The bottom panel 32 which forms one end of cavities 36 and 38 significantly improves the stability of the captured vortices 44 and 46. In the preferred embodiment, a top panel 34 is used to create a top horizontal vortex capturing cavity 40 which will trap a top vortex 48 and turn the airflow coming off the roof 18 downward towards the center line of the van base 26 further raising the base pressure.

FIG. 2B illustrates the trapping of the left side vortex 44 and the top vortex 48. The vortices 44, 46 and 48 turn the air 52 leaving the sides 20 and 22 and the roof 18 of the van towards the center of the van base 26 thereby raising the base pressure and reducing the drag. A dead arera space 42 is formed by the box-like area framed by panels 28, 30, 32 and 34 and the van base 26. FIG. 2C is a top plan view of the preferred embodiment showing the trapped vertical vortices 44 and 46 turning the flow 52 from the sides of the van inward towards the center line of the van back 26. Also shown is the rotational axis 50 of the top vortex 48 which takes the flow 52 leaving the roof 18 and directs the flow 52 downward, thereby further reducing the effective van base area.

A rear elevational view of the preferred embodiment 10 is shown in FIG. 2D where the horizontal top panel 34 is shown as located a dimension G from the top 18 of the van 12. In order to capture a stable vortex in the cavity 40 formed by vertical panels 28 and 30 and horizontal panel 34 and van base 26, the dimension G must be a fraction of the rearward extension of the panel L. The capture efficiency of the horizontal vortex 48 also improves when G/W−2D is much less than 1. The base panel 32 is shown mounted horizontally flush with the bottom 24 of the van 12 in order to shield the vortex capturing panels 28, 30, and 34 from the dirty flow field under the van 12 associated with the flow around and over the wheels 14 and axles 16. The base panel 32 is preferably not moved verticallv above the elevation of the van floor 24 to form a cavity similar to that formed by top panel 34, since, for the most part, the air stream 52 under the van 12 is pulled along with the undercarriage. It would, therefore, be difficult to capture a vortex of any appreciable strength which would turn the flow from under the van 12 upward at the van base.

FIG. 2E is a partial side elevational detail of the preferred embodiment 10 and FIG. 2F is a partial detail top plan view of the preferred embodiment 10. The vertical panels 28 and 30 shown in FIG. 2E have rounded edges 31. Similarly, as shown in FIG. 2F, the bottom panel 32 has a pair of rounded edges 33. Curved edges 31 and 33 are provided for aesthetic reasons and also to avoid sharp corners which may be easily bent if inadvertently impacted.

One of the major problems associated with prior art drag reducing attachments for the rear of blunt bodies is that the attachments may get in the way of the normal loading and unloading process of the van 12. Therefore it is important that the preferred embodiment 10 be adaptable to vans 12 having either a pair of flat rear swing opening doors or a roll up door. FIG. 2G illustrates a van 54 having a pair of flat rear doors 56 which open outwardly from the center line of the rear 26 of the body. The collapsible embodiment 58 of the invention includes a plurality of hinges 60 which allow panels 28, 30, 32 and 34 to fold up flat against the rear doors 56. Collapsible embodiment 58 is stored by releasing a latch 62 holding panel 34 to panel 28 and swinging top panel 34 downwardly to a vertical position against the other vertical panel 30. The bottom panel 32 is split into two sub panels 64. Another set of latches 62 hold one panel 64 to vertical panel 28 and another panel 64 to vertical

panel 30. By releasing latches 62 it is possible to allow the vertical panels 28 and 30 to be swung inwardly against rear doors 56. Base sub-panels 64 are then swung upwardly and locked by latches 61 against rear doors 56. In this manner the entire preferred collapsible embodiment 58 is stowed flush against the rear doors 56 and will not interfere with the opening or closing of the rear doors 56. FIG. 2H illustrates the manner in which the collapsible embodiment 58 is folded substantially flat against the rear doors 56 so that the doors 56 may open fully and be flush against the sides 20 and 22 of the van body 12.

While many vans 12 have flat rear swing doors, a number of vans have doors which roll up vertically and stow ust under the roof 18 of the van. An alternative collapsible embodiment 70 is illustrated in FIG. 2I and shown attached to the end of a van 66 having roll up doors 68. In this embodiment the vertical panels 28 and 30 are attached to the rear 26 by pivot arms 72. Collapsible embodiment 70 is stored by unlatching latch 74 of top panel 34 from the left side vertical panel 28 and swinging top panel 34 down against the right side vertical panel 30. The bottom panel 32 is split into two sub panels 64. The sub panels 64 are latched to each other by latch 74 and to the rear of the truck by latches 76. In order to store base sub-panels 64, they are first unlatched from each other by releasing latch 74 and then released from the rear of the van by releasing latch 76. The base sub-panels 64 are then swung upwardly about their hinges up against vertical panels 28 and 30 respectively where they are locked in place. Lastly, vertical panels 28 and 30 are then swung around against the sides of the van 20 and 22 respectively where they are held in place by latches 78. Pivot arms 72 are important in that they provide the offset required to bring the panels 28 and 30 flush against the sides of the van 66. While pivot arms 72 are described in the context of vans 66 having roll up doors 68 it is clear that pivot arms 72 could also be used with vans 54 having folding doors 56 as previously desribed in FIGS. 2G and 2H.

The basic preferred embodiment 10 may be either rigidly mounted to a van 12 or mounted in a collapsible manner as illustrated by embodiments 58 and 70. However, there are variations on the basic embodiment which may also prove to be efficient in reducing the base drag of a vehicle 12. According to one alternative embodiment 80, illustrated in FIG. 3, two vertical side panels 82 and 84 extend from a bottom panel 86 part way up the rear of the van terminating in a horizontal panel 88 which extends the entire width of the van. Alternative embodiment 80 also traps three vortices like the preferred embodiment 10, but the horizontal vortex which turns the flow from the roof downward is longer in alternative embodiment 80 while the vertical vortices which turn the flow from the sides of the van inward are shorter in the alternative embodiment.

Another alternative embodiment 90, illustrated in FIG. 4 includes a bottom panel 96, two vertical panels 92 and 94 extending the full height from the bottom to the top of the trailer and a top horizontal panel 98 extending between the two vertical panels 92 and 94. The difference between alternative embodiment 90 and the preferred embodiment 10 is that the distance D between the sides of the van and the panels 92 and 94 is larger than in the preferred embodiment. Therefore a pair of larger vertical vortices are captured and the effective base area of the van is further reduced over the preferred embodiment 10. However, in order to increase the distance D it is also necessary to increase the distance L by which the panels 92, 94, 96 and 98 extend rearwardly from the end of the van. Therefore, there is a trade off between the offset distance D and the extension distance L. Practical length restrictions may, therefore, preclude utilization of alternative embodiment 90. Moreover, due to the extended size of the panel a segmented, articulated stowage system would probably be required.

FIG. 5 illustrates the limiting condition where the vertical panels 92 and 94 of alternative embodiment 90 or vertical panels 28 and 30 of the preferred embodiment 10 are moved together so that they merge at the center line of the van 12. Accordingly, the limiting embodiment 100 has a single vertical panel 102 located at the center line of the van and a bottom panel 104 and a top panel 106 which define the upper and lower limits of the vortex capturing apparatus. The single vertical panel extends a distance L behind the van. In order to be effective the trailing distance L must be one or more times D where $D=W/2$. The limiting alternative embodiment 100 has several drawbacks. First, it can only capture two vortices 108 and therefore is not effective in turning the flow downwardly from the roof or upwardly from the base of the van. Second, the length L is much longer than any of the other alternative embodiments. Third, due to the extreme dimension L it would probably be necessary to make the apparatus with multi-articulated joints in order to be able to fold it into a stored position.

Another alternative embodiment 110 of the invention is illustrated in FIG. 6. Embodiment 110 includes a first and second vertical panel 112 and 114, a bottom panel 116 and a top panel 118. The difference between embodiment 110 and the previous embodiments is that neither the vertical panels 112 or 114 or the top horizontal panel 118 extend the rear height or width respectively of the rear of the van. Panels 112, 114, and 118 and van base 126 form a poorly defined cavity along the sides and roof of the van base. The base plate 116 isolates the cavity from the turbulence formed under the van.

The efficiency of the embodiment 110 in FIG. 6 can be improved by adding two diagonal panels 122 and 124 as illustrated in FIG. 7. According to the improved embodiment 120 a first diagonal panel 122 extends from the intersection of vertical panel 112 and top horizontal panel 118 to the intersection of the corner between the left side 20 of the van 12 and the top 18. Similarly, the other diagonal panel 124 extends from the intersection of vertical panel 114 and top horizontal panel 118 to the intersection between the top of the roof 18 and the right side 22 of the van. Diagonal panels 122 and 124 help contain the vortex by breaking it into three, more or less, straight lengths.

The embodiment 126 illustrated in FIG. 8 attempts to capture two vertical vortices and one horizontal vortex while utilizing the vertical panels to turn the airflow from the sides and roof of the van. The vertical panels 128 and 130 of embodiment 126 are flat but mounted at an angle other than perpendicular with respect to the rear 26 of the van.

A similar embodiment 132 employs a pair of curved vertical panels 134 and 136 to turn the flow from the sides and roof of the van. It is believed that curved panels 134 and 136 are probably more efficient in this context than the flat panels 128 and 130 such as illus-

trated in FIG. 8 for the purpose of turning the flow inwardly towards the rear of the van.

Lastly, FIG. 10 illustrates an embodiment 138 in which the general structure is identical to that of the preferred embodiment except that the two vertical panels 140 and 142 and the top horizontal panel 144 and bottom horizontal panel 146 are all curved in order to assist in drawing the airflow around towards the rear of the van.

The preferred embodiment 10 attaches to the back of a semi-trailer or trailer van 12. Vans 12 such as shown in FIG. 2A have a nominal width W=96" and a typical height from the floor to the roof of the van H=114". The preferred embodiment 10 includes end plates 28 and 30 of width L=between 40" and 56" and mounted offset from the sides 20 and 22 and roof 18 of the van D=12" and G=17" respectively. The preferred embodiment 10 has the following nondimensional ratios:

$$D/W=0.13,\ G/H=0.15 \text{ and } D/L=G/L=0.3$$

The above ratios are typical and preferred but may be adjusted to either improve the efficiency of capture of vortices or to move the panels 28 and 30 away from existing structural members on the van rear 26 which may interfere with installation. The preferred ranges of the ratios are:

$0.1 \leq D/W \leq 0.2$

$0.1 \leq G/H \leq 0.2$

$0.2 \leq D/L = G/L \leq 0.4$.

Testing of the preferred embodiment has shown that with $D/W=0.13$, $G/H=0.15$, and $D/L=G/L=0.3$ a 10.2% reduction in the aerodynamic drag of a typical tractor semi-trailer van rig 12 has been achieved. This 10.2% reduction is based upon the van rig 12 without a vortex capturing device affixed to the back having a drag coefficient of 0.6.

While the invention has been described with reference to the preferred embodiment thereof it will be appreciated by those of ordinary skill in the art that changes can be made to the structure and materials of the invention without departing from the spirit and scope thereof.

I claim:

1. An apparatus for reducing drag at the trailing end of a blunt body having a front end, a trailing end, a top surface, and a first and a second sidewall surface, said apparatus comprising:

first vortex capturing means connected to said trailing end for capturing and stabilizing a first vortex having an axis substantially parallel to the plane of said first sidewall surface, said first vortex capturing means including a first panel means attached to said trailing end and having a long axis substantially parallel to the plane of said first sidewall surface;

second vortex capturing means attached to said trailing end for capturing a second vortex having an axis substantially parallel to the plane of said second sidewall surface, said second vortex capturing means including a second panel means attached to said trailing end and having a long axis substantially parallel to the plane of said second sidewall surface;

third vortex capturing means connected to said trailing end for capturing a third vortex having an axis substantially parallel to the plane of said top surface, said third vortex capturing means including a third panel means attached to said trailing end and having a long axis substantially parallel to the plane of said top surface; and,

fourth panel means attached to the lower portion of said trailing end and having a long dimension substantially parallel to the plane of said top surface, said fourth panel means defining one end of said first and second vortex capturing means.

2. The apparatus of claim 1 wherein said first and second sidewall surfaces have a vertical height H and said first panel means and said second panel means are respectively located a distance D from the trailing edge of said first and second sidewall surfaces respectively so that the ratio D/H is less than 1.

3. The apparatus of claim 1 further including:

hinge means for connecting said first and second panel means to said trailing end and for permitting said first and second panel means to fold up substantially flat against said blunt body when not in use.

4. The apparatus of claim 3 further including:

first locking means for locking said first and second panel means in its operating position so that it can capture said first and second vortices.

5. The apparatus of claim 4 further including:

second locking means for locking said first and second panel means substantially flat against said blunt body when not in use.

6. The apparatus of claim 1 wherein said first and second panel means are curved in order to encourage the flow of air inwardly after it passes over the sides of said blunt body.

7. The apparatus of claim 1 wherein said third panel is curved in order to encourage air inwardly after it passes over the top of said blunt body.

8. The apparatus of claim 1 wherein said first and third panel means intersect at a first intersection line and said second and third panel means intersect at a second intersection line, said apparatus further including:

fifth panel means extending from said first intersection line to the extended intersection line between said top surface and said first sidewall surface; and,

sixth panel means extending from said second intersection line to the extended intersection line between said top surface and said second sidewall surface.

9. An apparatus for reducing drag at the trailing end of a blunt body having a front end, a trailing end, a top surface, and a first and a second sidewall surface, said appartus comprising:

first vortex capturing means connected to said trailing end for capturing and stabilizing a first vortex having an axis substantially parallel to the plane of said first sidewall surface, said first vortex capturing means including a first panel means attached to said trailing end and having a long axis substantially parallel to the plane of said first sidewall surface, said first panel means extending substantially the entire vertical height of said first sidewall surface;

second vortex capturing means attached to said trailing end for capturing a second vortex having an axis substantially parallel to the plane of said second sidewall surface, said second vortex capturing means including a second panel means attached to said trailing end and having a long axis substantially parallel to the plane of said second sidewall surface, said second panel means extending sub-

stantially the entire vertical height of said second sidewall surface; and,

third vortex capturing means connected to said trailing end for capturing a third vortex having an axis substantially parallel to the plane of said top surface, said third vortex capturing means including a third panel means attached to said trailing end and having a long axis substantially parallel to the plane of said top surface, said third panel means extending substantially the distance separating said first and second panel means.

10. An apparatus for reducing drag at the trailing end of a blunt body having a front end, a trailing end, a top surface, a bottom surface, a first sidewall surface and a second sidewall surface, said apparatus comprising:

a first vertical panel lying in a plane parallel to said sidewalls and attached to said trailing end at a point intermediate said sidewalls;

a first horizontal panel lying in a plane perpendicular to said sidewalss and attached to said trailing end so that said first vertical panel substantially contacts said first horizontal panel;

first vertical hinge means for attaching said first vertical panel to said trailing end; and,

first horizontal hinge means for attaching said first horizontal panel to said trailing end,

wherein said first vertical hinge means and said second horizontal hinge means permit said first vertical panel and said first horizontal panel respectively to be folded substantially flat against said blunt body when said panels are not deployed for reducing drag.

11. The apparatus of claim 10 further comprising:

a second vertical panel lying in a plane parallel to said sidewalls and attached to said trailing end so that it contacts said first horizontal panel.

12. The apparatus of claim 11 further comprising:

a second vertical hinge means for attaching said second vertical panel to said trailing end so that said second vertical panel can be folded subsantially flat against said blunt body when said second vertical panel is not deployed to reduce drag.

13. An apparatus for reducing drag at the trailing end of a blunt body having a front end, a trailing end, a top surface, a bottom surface, a first sidewall surface and a second sidewall surface, said apparatus comprising:

a first vertical panel lying in a plane parallel to said sidewalls and attached to said trailing end at a point intermediate said sidewalls;

a first horizontal panel lying in a plane perpendicular to said sidewalls and attached to said trailing end so that said first vertical panel substantially contacts said first horizontal panel; and,

a second horizontal panel lying in a plane substantially parallel to the plane of said first horizontal panel and connected to said first vertical panel at a location separated from the point of contact of said first horizontal panel to said first vertical panel.

14. An apparatus for reducing drag at the trailing end of a blunt body having a front end, a trailing end, a top surface, a bottom surface, a first sidewall surface and a second sidewall surface, said apparatus comprising:

a first vertical panel lying in a plane parallel to said sidewalls and positioned adjacent said trailing end at a location intermediate said sidewalls;

a first horizontal panel lying in a plane perpendicular to said sidewalls and positioned adjacent to said trailing end so that the plane of said first vertical panel intersects the plane of said first horizontal panel; and,

a second vertical panel lying in a plane parallel to said sidewalls and positioned adjacent to said trailing end so that the plane of said second vertical panel intersects the plane of said first horizontal panel.

15. An apparatus for reducing drag at the trailing end of a blunt body having a front end, a trailing end, a top surface, a bottom surface, a first sidewall surface and a second sidewall surface, said apparatus comprising:

a first vertical panel means for lying in a plane parallel to said sidewalls and positionable adjacent to said trailing end at a location intermediate said sidewalls when deployed for use;

a first horizontal panel means for lying in a plane perpendicular to said sidewalls and positionable adjacent to said trailing end so that the plane of said first vertical panel intersects the plane of said first horizontal panel when deployed for use; and,

panel folding means for attaching said first vertical panel means and said first horizontal panel means to said blunt body,

wherein said panel folding means permits said first vertical panel means and said first horizontal panel means respectively to be folded substantially flat against said blunt body when said panel means are not deployed for reducing drag.

16. An apparatus for reducing drag at the trailing end of a blunt body having a front end, a trailing end, a top surface, a bottom surface, a first sidewall surface and a second sidewall surface, said apparatus comprising:

first vertical panel means for capturing a first vortex lying in a plane parallel to said sidewalls and positionable adjacent to said trailing end at a first location intermediate said sidewalls when deployed to reduce drag; and,

a second vertical panel means for capturing a second vortex lying in a plane parallel to said sidewalls and positionable adjacent to said trailing end at a second location different from said first location and intermediate said sidewalls when said second panel means is deployed to reduce drag wherein said first and second vortices cause the flow of air to flow around the first and second sidewall surfaces towards the center line of said blunt body.

* * * * *

United States Patent [19]

Wheeler

[11] **4,455,045**

[45] **Jun. 19, 1984**

[54] **MEANS FOR MAINTAINING ATTACHED FLOW OF A FLOWING MEDIUM**

[76] Inventor: **Gary O. Wheeler, 1080 Vallejo Cir., Costa Mesa, Calif. 92626**

[21] Appl. No.: **314,735**

[22] Filed: **Oct. 26, 1981**

[51] Int. Cl.³ **B62D 35/00**

[52] U.S. Cl. .... **296/1 S; 105/2 R; 244/53 B; 244/200**

[58] Field of Search .... **244/200, 53 B; 296/1 S, 296/91, 24 C; 105/2 R, 2 A**

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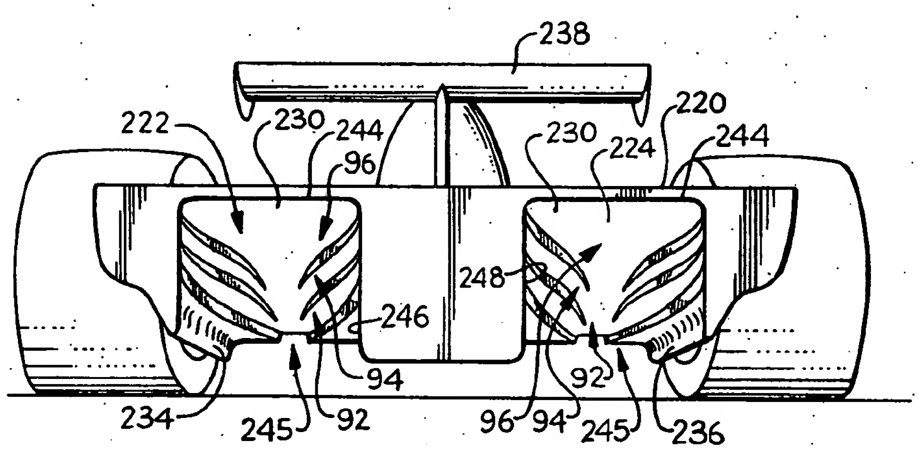
Primary Examiner—Richard A. Bertsch
Attorney, Agent, or Firm—George W. Finch

[57] **ABSTRACT**

One or more channels whose edges generate streamwise vortices from heights coincidental with a local flow-control surface into the channels are used to maintain attached flow of a fluid medium flowing therepast, even in areas of severe regional adverse pressure gradients. The channels are generally triangular in shape with the apex forwardmost in the flow. The channels work very effectively when nested in series and are most effective when the channels extend to the trailing edge of a flow-control surface.

53 Claims, 16 Drawing Figures



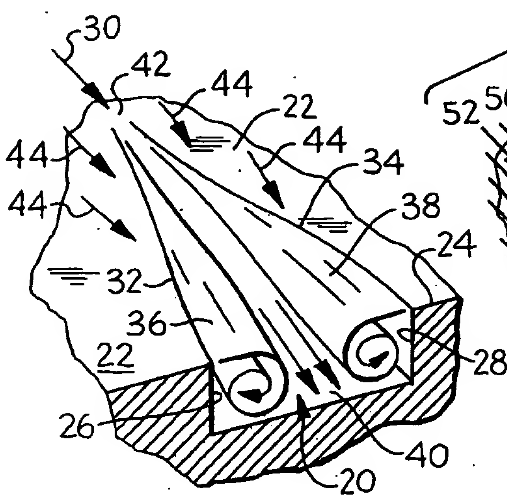


FIG. 1

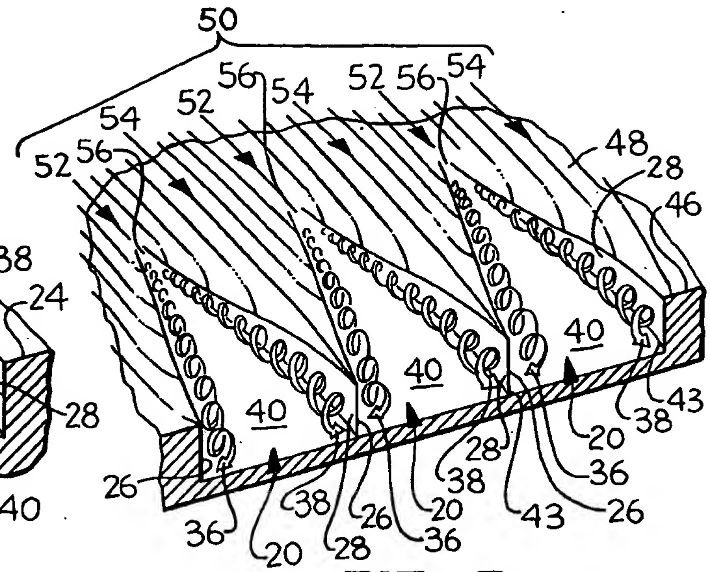


FIG. 2

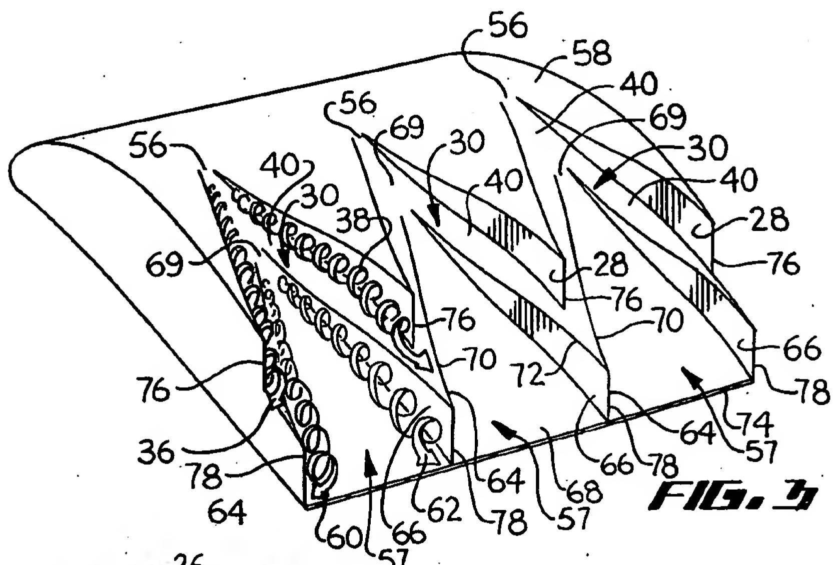


FIG. 3

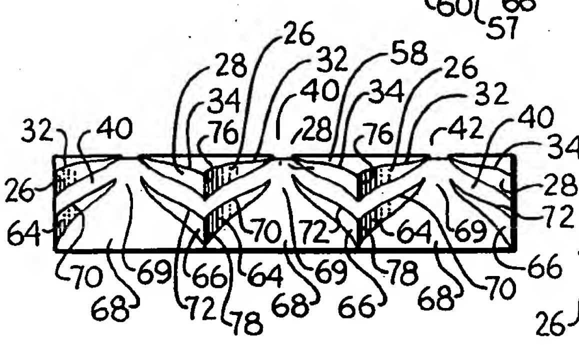


FIG. 4

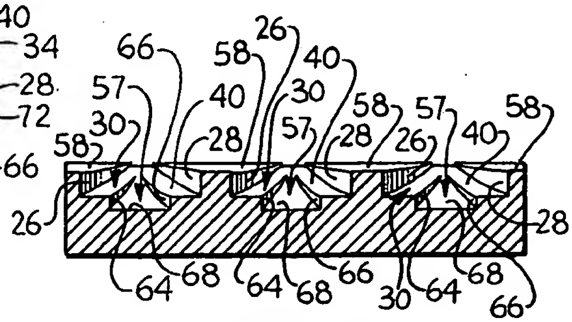


FIG. 5

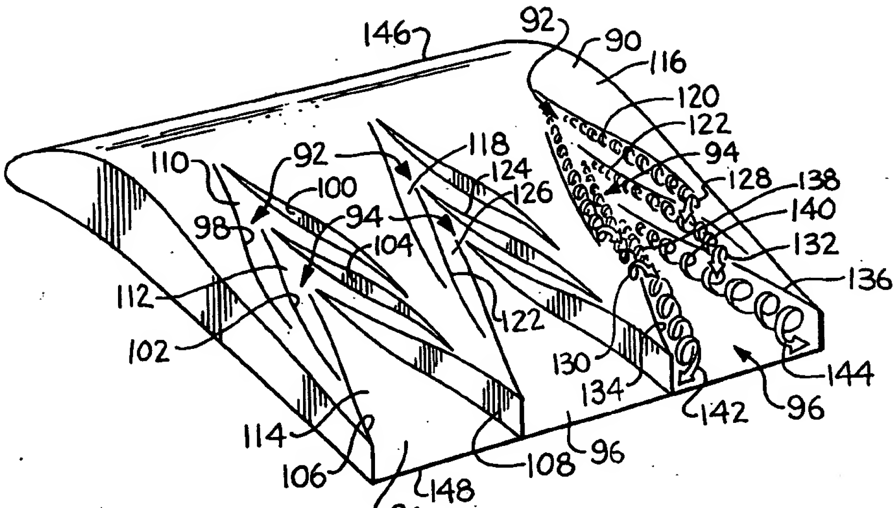


FIG. 6

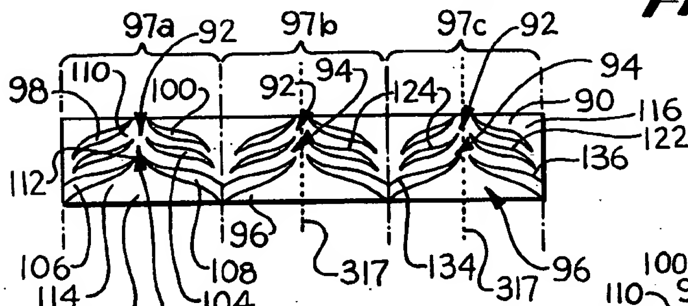


FIG. 7

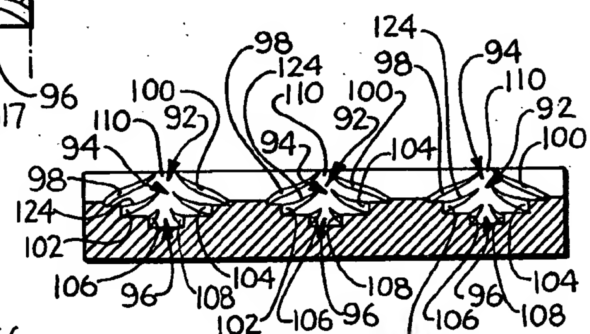


FIG. 8

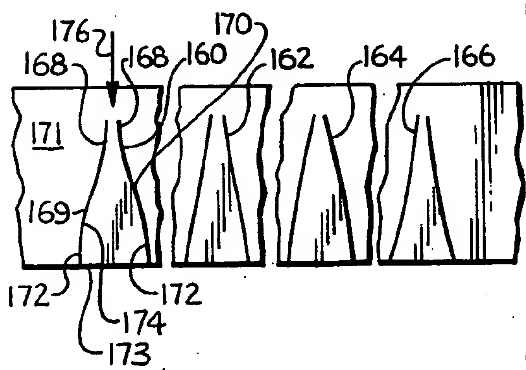


FIG. 9

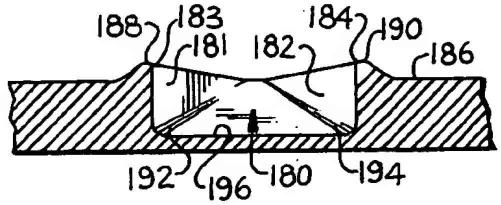


FIG. 10

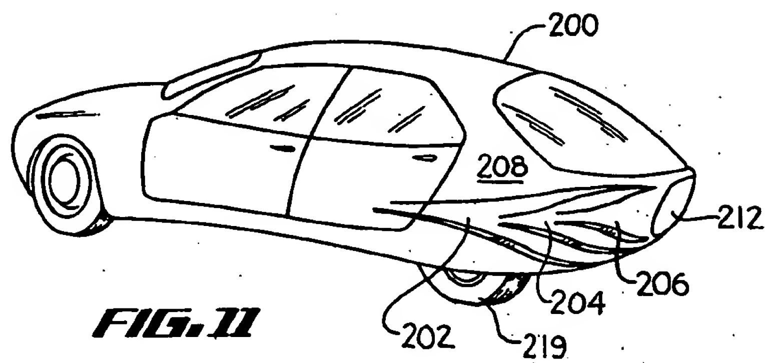


FIG. 11

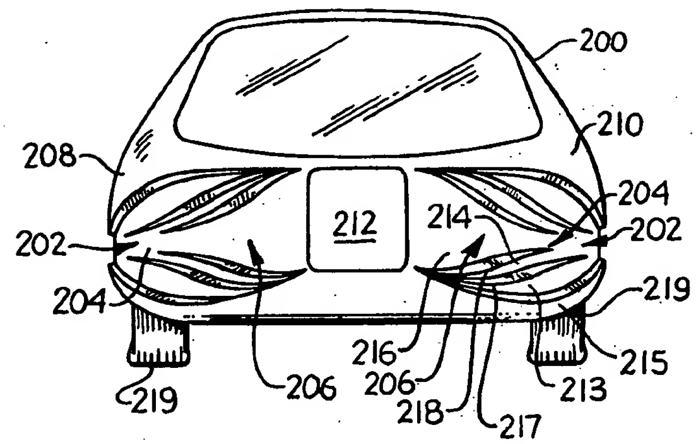


FIG. 12

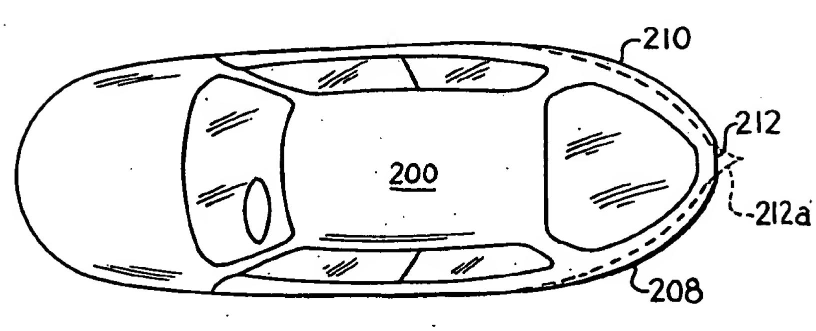


FIG. 13

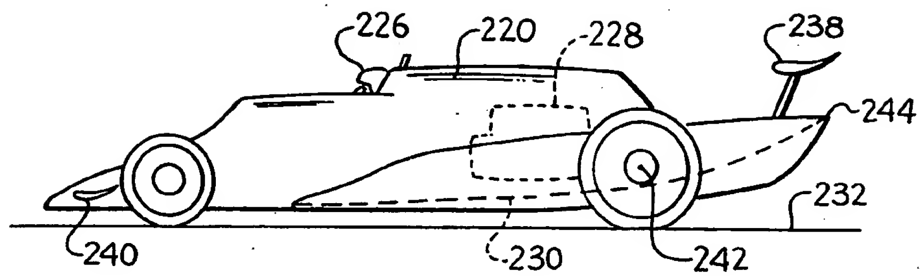


FIG. 14

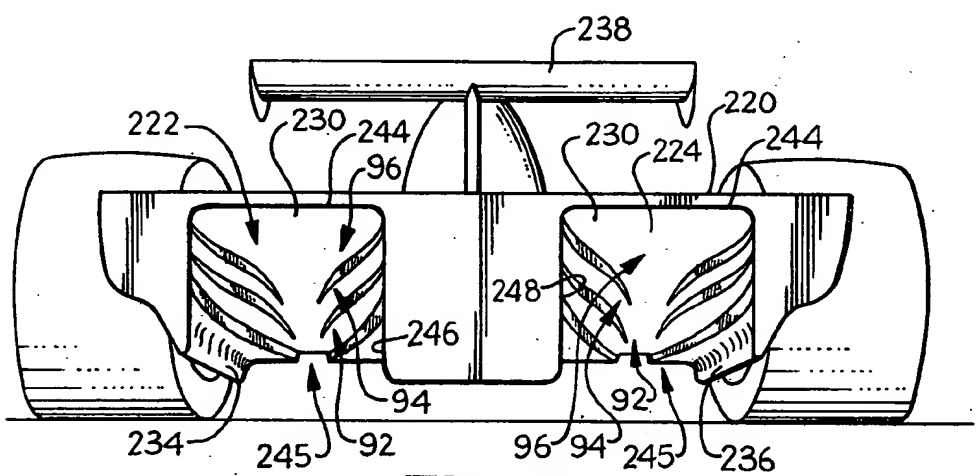


FIG. 15

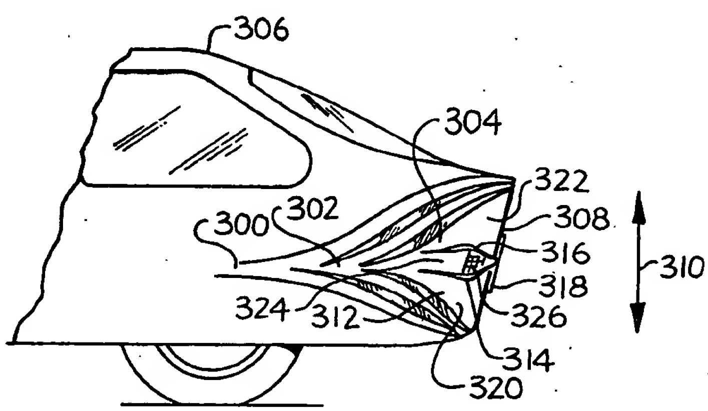


FIG. 16

MEANS FOR MAINTAINING ATTACHED FLOW OF A FLOWING MEDIUM

BACKGROUND OF THE INVENTION

There are many applications where it is desired to have a low drag method of delaying or preventing flow separation between a flowing fluid and a flow-control surface in regions where, due to contours of the flow-control surface, the fluid's boundary layer is subjected to adverse pressure gradients normally sufficient to cause flow separation.

The purpose of such boundary layer control is to delay or prevent flow separation. When a viscous fluid boundary layer flows from a region of low static pressure to a region of high static pressure, as when passing over a wing toward the trailing edge, it is said to be in a region of adverse pressure gradient. This results in forces tending to retard the boundary layer which can become strong enough to arrest and reverse the flow. This in turn causes the fluid to separate from the flow-control surface and no longer be influenced predictably by the downstream contour. The result is increased drag due to the large cross-sectional area of separated flow in the wake of the flow control surface. In the case of a stalled wing, degraded lift is accompanied by a rise in drag.

One useful but relatively high drag method heretofore used is to generate streamwise vortices for the purpose of mixing free-stream flow with the boundary layer to delay or totally prevent flow separation. Generally, there are two categories of vortex generators. The first category covers those devices that protrude well into and usually somewhat above the 99% boundary layer height. Included in this category are conventional vane-type vortex generators as well as prior art ramp-type generators of varying planform shapes. Unfortunately, these devices achieve boundary layer control only at the penalty of considerable drag. An example of the ramp-type vortex generator is shown in STEPHENS, U.S. Pat. No. 2,800,291. STEPHENS teaches the use of ramp-type generators positioned in rows at right angles to the flow with the generators extending back to some intermediate position on the flow-control surface.

The second and less familiar category of vortex generators uses the "Taylor-Goetler instability" to generate streamwise vortices within the boundary layer when a fluid is caused to flow over a concave surface. This alternative is more subtle, but the vortices are still left to travel downstream on the primary flow-control surface, causing turbulent mixing between the boundary layer and the free-stream and resulting in an unwanted drag increment. Devices of this category are disclosed by KUETHE in U.S. Pat. Nos. 3,578,264 and 3,741,285. KUETHE teaches selected discontinuities positioned both above and below the level of the adjacent flow-control surface which in effect squeeze the boundary layer between adjacent protrudences to eject a vortex into the boundary layer and cause mixing.

It is unfortunate that the prior art vortex generators either operate relatively ineffectively or cause an excess in drag since devices are needed which enable the turning of air flows about sharp cambers. Normally, conventional attempts to reduce the wake and hence the drag of a body moving with respect to a fluid medium by mere curved and tapered body contours in the rear result in pressure recovery regions that are limited by flow separation occurring in the regions of adverse pressure gradients. The flow separation in such instances normally occurs downstream of a body's maximum cross-section.

For example, road vehicles, which are designed for low drag must include very gentle rear deck curvatures to maintain attached flow over a substantial region behind the maximum cross-section. Except in the instance of specially constructed high-speed race cars, full recovery cannot be achieved in the length available on roadable vehicles. A Porsche 924, which is a well streamlined vehicle still has a coefficient of drag (C_D) of approximately 0.35. If all the wake drag caused by flow separation could be eliminated, the C_D could approach 0.25 and result in a considerable fuel savings or speed capability. For comparison, a utilitarian car, such as a Volkswagon Rabbit, (where there is very little attached flow past the maximum cross-section) has a C_D of about 0.45. Elimination of the wake drag caused by flow separation could in theory reduce the C_D to about, 0.30 with no other changes to the vehicle. Although there have been countless attempts to reduce the drag of road vehicles by maintaining attached flow, considerations such as structural weight and aesthetics restrict the length of road based vehicles to such an extent that at some point the body contours must be so abrupt that adverse pressure gradients occur. These produce flow separations which generate a relatively large separation wake. The wake is aerodynamically disadvantageous causing drag and increased fuel consumption especially at higher cruising speeds. This heretofore unavoidable wake is the reason visibly streamlined road cars have heretofore exhibited only small drag advantages over properly designed vehicles with bluff or abrupt tails.

Some vehicles have used wing-like airfoils as turning vanes to assist in directing external flow to reduce the adverse pressure gradients. However, the mass flow of air moved by these add-on devices never comes close to filling the large wake behind a body proportioned like a normal road vehicle. Therefore, the effect is helpful but minor.

There have been suggestions that the application of powered suction at discrete locations near the rear of a vehicle might provide a method for achieving wake reduction. However, wind tunnel studies show that the power required by such suction systems rivals the amount needed to power the original standard vehicle and therefore does not accomplish the overall result of reducing the total energy requirement of the vehicle. If a method could be found to reduce the energy required to move a poor slenderness ratio body through the air by providing means to maintain attached flow in the areas of adverse pressure gradients, the reduced energy requirement would translate directly into reduced fuel consumption.

As reported in NACA Research Memorandum, A8F21 entitled "An Experimental Investigation of a Large Scale of Several Configurations of a NACA Submerged Air Intake", published 19 Oct., 1948, devices are known for generating strong vorticity by passing flow over the sharp corners of the intersections between channel walls and a reference body surface adjacent an inlet ramp surface. Typically, NACA inlets have a ramp surface of generally V-shape which extends to an inlet duct lip thereabove and is bounded on the opposite sides by reflexed sidewalls extending upwardly to the body surface at approximately 90°. How-

ever, since all NACA inlets are intended to be inlets for rectangular cross-section intake ducts, their sidewalls must become parallel to the connecting duct sidewalls, hence the reflex and inlet duct lip must be carefully designed. The inlet lip forms the beginning of a fourth wall for the duct at the location of flow entry into the vehicle. The planform of a NACA inlet is always defined by the chosen ramp angle, that is, the included angle between the flat ramp floor and the body's external body surface. The length of the NACA inlet is always a direct result of that choice of angle. This grossly reduces the design choices available, especially when it is desired to reduce the aerodynamic drag of a body having a poor slenderness ratio.

The NACA inlets were designed to be located in regions of positive pressure since their purpose is to take air on board a vehicle, either to provide combustion air to an engine, flow to a heat exchanger or simply provide ventilation. NACA inlets are known to perform poorly in regions of great negative static pressure. NACA inlets are never used for the purpose of influencing external flow conditions on a basic body, other than to take in air and have never been used for the purpose of achieving aerodynamic drag reduction for a body passing through a flowing medium.

Therefore, even though various types of devices are known which produce vortices, none are effective in assuring attached flow in an adverse pressure gradient region with low drag.

BRIEF DESCRIPTION OF THE PRESENT INVENTION

Generally, the present invention is embodied in one or more three-sided submerged channels in a flow-control surface. Each channel includes two divergent walls forming a generally V-shaped ramp therebetween sloped so that the channel widens and deepens toward downstream flow. The intersection between the flow-control surface adjacent the channels and the divergent wall preferrably has a sharp radius of near 90° to generate strong vortices which rotate toward each other. The vortices energize the flow in the channel maintaining flow attachment to the ramp thereof and also maintaining flow attachment to the flow-control surface upstream and beside the channel. The channel itself is aligned generally with the direction of local flow in front of the V-point thereof and to function most efficiently, the front of the channel should be at least adjacent a region where attached flow would exist if the channel was not present. The exit of the channel or the last channel when multiple channels are placed in series, preferrably is positioned at or near the rearmost edge of the flow-control surface to release the flow at a revised height or width and thereby effect a reduction in wake cross-section area.

The channels are very effective when used in series cascade with the last channel in the cascade ending at the trailing edge of the flow-control surface. The present invention assures boundary layer control on the flow-control surface through simple thinning of the boundary layer with dynamic turbulent mixing between vortices, boundary layer, and the free-stream fluid constrained within the submerged channels to prevent adverse drag.

As is known, there is a tendency of a fluid to form a strong vortex when caused to flow over a sharp edge at an appropriate angle. This phenomenon is seen along the sharp leading edges of delta wings at high angles of attack. In the present invention, the submerged channels have a nominally triangular planform shape permanently formed into the flow-control surface. These channels have sharp upper edges for effective vortex formation, divergent sidewalls essentially normal to the flow-control surface, and floor contours arranged to immediately conduct the streamwise vortices below the level of the local flow control surface. When the submerged channels are nested together in a proper overlapping manner, creating a streamwise cascade, new vortices can be generated downstream as often as required to replace vortices generated upstream which are about to burst and degenerate because of a strong adverse pressure gradient.

Vortex bursting is characterized by a sudden and pronounced increase in vortex diameter followed by disintegration and decay. This natural phenomenon normally would occur downstream of the flow-control surface's trailing edge. However, as the amount of adverse pressure gradient is increased, the location of vortex bursting moves forward until it coincides with a trailing edge. At this stage, the maximum effect of the invention is realized. Any further increase in adverse pressure gradient simply drives the vortex bursting location farther forward toward the vortex source and causes flow separation upstream of the trailing edge. As a consequence, and because pressure recovery requirements are frequently most severe toward the trailing edge of a flow-control surface, cascading the submerged channels of the present invention is a very effective way to utilize the invention when extreme adverse pressure gradients are encountered, such as, at the rear of a roadable vehicle, the aerodynamic tunnel of a ground-effects race car or the aft fuselage of a rear loading cargo aircraft.

It is therefore an object of the present invention to provide means which can prevent flow separation from a flow-control surface, such as a wing, flap, propeller, windmill blade, airfoil, fan, rotor, stator, inlet, diffuser or the inside radius of bends in pipes, ducts and engine ports.

Another object is to provide means to facilitate aggressive boat-tailing at the rear of a poor slenderness ratio body such as a commonly shaped automobile, aircraft, golf driver club, or boat where considerations such as interior volume and restricted length make effective rear end streamlining impossible.

Another object is to provide means for eliminating the need for long tapered streamlined tails on vehicles while decreasing the drag of the vehicle and thereby eliminating the attendant penalties of length, weight and wetted area of streamlined tails.

Another object is to provide means which are relatively easy to design and manufacture for maintaining attached flow to a flow-control surface in regions of adverse pressure gradients.

Another object is to provide low drag means for controlling flow separation.

Another object is to provide means for reducing aerodynamic drag of bodies immersed in a flowing medium when such bodies have poor slenderness ratios.

Another object of the present invention is to provide an aerodynamic improvement for application to a conventional land vehicle which is versatile enough to be blended into various styling themes and therefore provide a pleasing appearance as well as an increased efficiency for the vehicle.

These and other objects and advantages of the present invention will become apparent to those skilled in the art after considering the following detailed specification which covers preferred embodiments thereof in conjunction with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a single submerged channel constructed according to the present invention showing the vortices formed thereby;

FIG. 2 is a perspective view of submerged channels embedded in a flow-control surface constructed according to the present invention including indications of the fluid flow thereabout;

FIG. 3 is a perspective view of a wing segment including a spanwise array of submerged channels nested in cascade which are constructed according to the present invention;

FIG. 4 is a rear view of the wing segment in FIG. 3;

FIG. 5 is a typical spanwise cross-sectional view of the wing segment of FIG. 3;

FIG. 6 is a perspective view of an airfoil constructed with an alternate form of the submerged channels of the present invention nested in cascade;

FIG. 7 is a rear view of the airfoil of FIG. 6;

FIG. 8 is a typical spanwise cross-sectional view of the airfoil of FIGS. 6 and 7;

FIG. 9 is a diagram of typical planform shapes for submerged channels constructed according to the present invention;

FIG. 10 is a lateral cross-section of an alternate form of the invention having lips that protrude into the boundary layer;

FIG. 11 is a perspective view of a roadable automobile showing the application of the present invention to maintain attached flow and thereby eliminate flow separation from the rear thereof;

FIG. 12 is a rear view of the automobile of FIG. 11;

FIG. 13 is a top plan view of the automobile of FIGS. 11 and 12;

FIG. 14 is a side view of a ground effects race car;

FIG. 15 is a rear view of the race car of FIG. 14 showing the application of the present invention to the ground effect tunnels thereof; and

FIG. 16 is a side elevational view of the rear fender area of a production automobile with the present invention incorporated therein.

DETAILED DESCRIPTION OF THE SHOWN EMBODIMENTS

Referring to the drawings more particularly by reference numbers, number 20 in FIG. 1 refers to a boundary layer control channel 20 constructed according to the present invention submerged in the flow-control surface 22 of a body 24. The channel 20 includes a pair of sidewalls 26 and 28 which are generally perpendicular to the surface 22 and converge toward each other as they progress upstream to the flow of fluid medium 30. The sidewalls 26 and 28 form relatively sharp edges 32 and 34 respectively, with the surface 22 for generating a pair of counter-rotating vortices 36 and 38 from the flow 30 which passes thereover. The channel 20 is bounded at its bottom by a lower triangular surface 40 which in cross-section is generally parallel to the surface 22, but in length extends from beneath the flow-control surface 22 upwardly to a point of intersection 42 therewith at the upstream end of the walls 26 and 28. The intersections 43 between the sidewalls 26 and 28 and the floor surface 40 are shown with sharp radii but radii up to the radii of the local radii of the adjacent vortex 36 or 38 can be used. As shown, the edges 32 and 34 have an ogee shape and the height of the walls 26 and 28 at any location therealong and hence the distance the lower surface 40 is from the surface 22 at any point is designed so that the vortices 36 and 38 preferrably are completely submerged within the channel 20 to prevent drag. As can be seen from the flow arrows 44, the vortices 36 and 38 tend to thin the boundary layer keeping attached flow on the surface 22 and on the floor surface 40 of the channel 20.

A different visualization of this process is shown in FIG. 2, wherein a plurality of channels 20 are provided submerged in a body 46. The vortices 36 and 38 of opposite rotations, vortex 36 rotating clockwise and vortex 38 rotating counterclockwise as viewed to the upstream, are formed by drawing flowing fluid from the lowest portion of the boundary layer of the flow-control surface 48. This causes the boundary layer to thin as the flow follows the streamlines indicated by the arrows 50 which generally curve into the channels 20. An increase in space between adjacent streamlines as the flow progresses downstream indicates a thinning of the boundary layer which protects against flow separation such as might be caused by regional adverse pressure gradients. The streamlines indicated by the arrows 52 and 54 do not curve because of their symmetrical position with respect to the apices 56 of the channels 20 in the case of arrows 52, their symmetry between adjacent channels 20 in the case of arrows 54. If the channels 20 are to be divided by an aerodynamic fence, not shown, it should be run along the length of arrows 52 or 54.

The vortices 36 and 38 travel downstream within the channels 20 adjacent the channel walls 26 and 28 effecting boundary layer control on the channel walls 26 and 28 and the floor surfaces 40 through dynamic turbulent mixing. The local flow velocity on the channel floor surface 40 is maintained at a very high percentage of free-stream velocity and the flow is well protected against incipient separation.

Although streamwise vortices have a low rate of viscous decay, they are subject to a natural mechanism of breakdown that begins with an abrupt bursting or expansion of the vortex diameter, after which the vortex is no longer effective in terms of boundary layer control. As explained previously, the actual location of this bursting point is dependent upon the regional adverse pressure gradient. If the adverse pressure gradient is large enough, it is possible to burst the vortices 36 and 38 soon after they are formed within the channels 20.

As shown in FIG. 3, it is possible to nest one or more similar channels 57 within the channels 30, thereby forming a flow-wise cascade in an airfoil segment 58 to counteract any tendency for the vortices to burst. With this nested geometry, discrete new streamwise vortices 60 and 62 are generated from fluid drawn off the floor surface 40 of the preceeding channel 30. The general flow streamlines are analogous to those shown in FIGS. 1 and 2. These freshly generated vortices 60 and 62 are usually as strong as the original vortices 36 and 38. They effect boundary layer control further downstream because they are formed farther aft and therefore can resist bursting further aft along the airfoil segment 58. The channels 57 have sidewalls 64 and 66 similar to sidewalls 26 and 28, floor surfaces 68 which intersect the floor surfaces 40 of the channels 30 at their apices 69, and edges 70 and 72 similar to the edges 32 and 34.

This can be further visualized by reference to FIGS. 4 and 5. The cascade concept shown in FIGS. 3, 4 and 5 is particularly useful because the vortices 60 and 62 in the downstream channels 57 maintain full boundary layer control effectiveness even if the previously generated vortices 36 and 38 were subject to bursting as far forward of the trailing edge 74 of the airfoil segment 58 as the aft terminii 76 of the sidewalls 26 and 28. It should be noted, that the aft termini 76 of the walls 26 and 28 are relatively sharp and streamlined for a low drag release of the vortices 36 and 38 formed adjacent thereto. To be most effective in preventing vortex bursting and the large drag penalty associated therewith, it is preferrable that the aft termini 78 of the walls 64 and 66 of the last channels 57 in the cascade be at or closely adjacent the trailing edge 74. Of course, this is not required when a negative pressure gradient sufficient to cause the vortices 60 and 62 to burst will never be present at the trailing edge 74 under the expected operating conditions.

In FIGS. 6, 7 and 8, an alternate form of submerged vortex generating channels nested in cascade is shown in connection with an airfoil segment 90. In the form illustrated, three channels 92, 94 and 96 are positioned in each cascade *97a*, *97b* or *97c* with each channel 92, 94 and 96 having sidewalls 98 and 100, 102 and 104 and 106 and 108 and floor surfaces 110, 112 and 114 respectively. The channels 92, 94 and 96 are similar to channels 20 and 57, except that the floor surfaces 110 and 112 are reenterant with the flow control surface 116. This arrangement of the floor surfaces 110, 112 and 114 has proved to function at least as well as the embodiment shown in FIGS. 3 through 5 and offers possible advantages in areas such as structural integrity, manufacturing cost, and asthetics.

There is a well known tendency for adjacent streamwise vortices of the same sign of rotation to join and roll into a single vortex sheet. This form of the invention uses that tendency to good effect. The vortices 118 and 120 of the channel 92, tend to roll over the adjacent edges 122 and 124 of the adjacent channel 94 to join with the vortices 126 and 128 generated thereby and to form combined vortices 130 and 132. In so doing the vortices 118 and 120 do not stick up into the adjacent flow field to cause undue drag. The vortices 130 and 132 likewise have a tendency to roll over the adjacent edges 134 and 136 respectively of the channel 96 to combine with the vortices 138 and 140 generated thereby and to form combined vortices 142 and 144. Although this is shown for the case of three channels 92, 94 and 96, it can be repeated as often as desired to extend the benefits of boundary layer control from the leading edge 146 to the trailing edge 148 of the airfoil segment 90, should such be necessary.

The nominal included planform angle between the divergent walls 26 and 28, 64 and 66, 98 and 100, 102 and 104 or 106 and 108 should be near 30° although generally good results are obtainable between 15 and 45 degrees. At narrower included angles, vortex formation is strong but the vortices within a particular channel tend to touch and because they are rotating in opposite directions one may roll above the other in an asymmetric manner extending into the surrounding flow and causing drag and unstable performance. Conversely, when the included angles are too wide, vortex formation tends to be weak leading to potentially premature vortex bursting.

Since the flow-control surface 22, 48 or 116 and the channel floor surface 40, 68, 110, 112 or 114 may be highly cambered from front to rear, it is not appropriate to refer to a simple angle between the channel floor surface 40 and the flow-control surface thereabout. However, the channel floor contour is fundamentally important because the rate of expansion of channel volume must not be so great as to cause flow separation within the channel. Therefore, abrupt changes in depth or cross-sectional areas of the channel 20, 57, 92, 94 or 96 are to be avoided. As a guide to contouring the channel floor the local depth at any channel station should not be made greater than half the local planform width because two rolled up sheet vortices must be accommodated side-by-side within the confines of the channel. Said another way, the minimum cross-section aspect ratio ($width_2$/area) is approximately 2. In general, cross-section aspect ratios of 3 and above provide excellent protection from choosing a floor contour so radical as to cause flow separation in the channel itself.

As will be discussed hereinafter, the walls 26 and 28, 64 and 66, 98 and 100, 102 and 104, or 106 and 108 need not be at right angles to either the flow-control surface or the channel floor. Therefore, when the channels are to be stamped or molded, very large draft angles are tolerable. It is also acceptable to radius the intersections such as intersections 43, of the channel walls and floor with radii no larger than the outer radius of the local vortex.

FIGS. 6, 7 and 8 illustrate a specific example of a modified Liebeck airfoil segment 90 which was tested in a wind tunnel. The particular modified Liebeck airfoil section was chosen for the airfoil segment 90 because of its known high-lift and low-drag characteristics. A 10" chord, 16" span wing without end plates was suspended at the center of the wind tunnel and tested at 38 ft/sec. wind speed. The low Reynolds number of 200,000 was chosen because of an interest in a high-performance windmill blade application. To insure satisfactory vortex formation at air speeds as low as 15 mph, each channel was made 6" in length. The modified wing was built with five span-wise rows, each containing six submerged vortex generating channels nested in streamwise cascade similar to that shown in FIG. 6. The clean wing yielded a maximum 3-D lift coefficient of 1.03 at an angle of attack of 16°. The wing modified with the present invention developed a maximum 3-D lift coefficient of 1.48 at an angle of attack of 26°. This is a very high three-dimensional lift coefficient considering the test wing's aspect ratio was only 1.6.

At lower angles of attack where neither wing experienced detectable flow separation, the modified wing exhibited a lift/drag advantage ranging from 14% greater lift at equal drag, to 20% less drag at equal lift. The 99% boundary layer, is the thickness of the boundary layer at which the relative velocity between the surface and the fluid is 99% of that of free-stream. At the trailing edge of the unmodified wing the 99% boundary layer was 0.62" thick. However, along the modified wings trailing edge, the 99% boundary layer was only 0.03" thick. Therefore, the tests showed that effective delay of flow separation by thinning the boundary layer can be achieved with the present invention without the drag increment normally associated with the prior art devices.

FIG. 9 illustrates several typical planform contours useful with the present invention, including an ogee contour 160, a straight triangular contour 162, a convex

triangular contour 164 and a concave triangular contour 166. The contours 160, 162, 164 and 166 are only typical of possible shapes. However, the ogee contour 160 seems to have advantages in that the forward portions 168 of its sidewalls 169 and 170 fair easily into the adjacent surface 171, the trailing portions 172 of the sidewalls 169 and 170 fairs into an adjacent channel or the trailing edge 173 at a very small included terminus angle, and its center portion 174 has a sufficent angle with respect to the normal flow direction, as indicated by the arrow 176, or flows off angle therefrom, to produce the strong vortices desired.

In FIG. 10, a channel 180 is shown whose sidewalls 181 and 182 upper edges 183 and 184 are in the form of upwardly extending lips which protrude above the adjacent flow-control surface 186. Such lip structures even with the rounded edge cross-sections 188 and 190 tend to have greater drag than fully submerged and sharp geometries. Nevertheless, they are quite functional for use when structural or molding considerations do not allow sharp edges, like edges 32 and 34 of the preferred cross-section. As shown, the intersection 192 and 194 of the sidewalls 181 and 182 with the floor surface 196 is also rounded. As aforesaid, this does not adversely affect the performance of the channel 180 so long as the intersection 192 and 194 do not extend more than halfway up the walls 181 and 182.

A practical example of the present invention's ability to maintain attached flow in an extreme adverse pressure gradient situation is shown in FIGS. 11 through 13. FIG. 11 is a perspective view of a detailed 1/10th scale wind tunnel model, 200 of a Gas Camel automobile (trademark of Daniel S. Gurney, Newport Beach, Ca.) employing the present invention in the form of channels 202, 204 and 206 on the opposite sides of the model. The channels 202, 204 and 206 which are similar to the channels 92, 94 and 96 of FIG. 6, are positioned on the opposite rear fenders 208 and 210 of the model 200, in order to permit radical "boat-tailing". In this instance, the choice of size for the channels 202, 204 and 206 was largely one of asthetics, they in fact being large enough to generate vorticity below 5 mph on a full-sized car. The radical extent of the "boat-tailing" accomplished in just 3' of scale rear-axle overhang is shown in FIG. 13. Upon reaching the rear license plate area 212 of the model 200, the flow on each side of the model is turned through 65°. Although it is difficult to see, the floor surfaces 213 and 214 of the channels 202 and 204 are not parallel to the flow-control surface 215 thereabout or the floor surface 216 of the channel 206. The angle chosen tilts the edges 217 and 218 of the channels 204 and 206 upwardly into the 3-D airstream in channels 202 and 204 to assure vortex formation. This is especially important in the lower half of the channels behind the rear wheels 219 which disturb the flow and make vortex formation difficult.

Wind tunnel tests at a Reynolds number of 600,000 verified the maintenance of fully attached flow to the rear area 212 of the model 200. Since the rear area 212 had an area reduced to little more than the cross-sectional area of a rear license plate, there was a large reduction in the wake of separated flow behind the model 200. If the flat rear license plate area 212 was not legally required, the opposite rear fenders 208 and 210 could have been merged together in the form of a tiny stinger 212*a* as shown in dotted outline in FIG. 13, for still lower drag.

The model 200 as pictured, yielded a drag coefficient $C_D=0.157$ when no air gaps were present between the tires and the ground plane. For comparison, when the channels 202, 204 and 206 were filled in and faired so as to be removed, the drag of the model 200 rose nearly 30% to $C_D=0.203$. The model 200 with the channels 202, 204 and 206 was yawed up to 40° in the wind tunnel without provoking flow separation on the downwind flank. This presented the interesting spectacle of flow on the downwind side of the yawed model 200 leaving the rear 212 in a direction that was literally 15° upstream.

When a duplicate model without the channels 202, 204 and 206 was given a long tapered tail in an attempt to equal the low drag achieved by the channels 202, 204 and 206, a rear axle scale overhang of 5' was required to provide sufficient pressure recovery zone length for attached flow to be maintained to the same size rear area 212. However, the boundary layer was quite thick and the best C_D that could be obtained was 0.162 making it appear that the conventionally streamlined, long-tailed model could not be made to equal the low drag of the model 200. Furthermore, 20° of yaw angle would provoke flow separation on the downwind side of the long tail indicating comparatively poor aerodynamic stability in cross winds. These tests show that in some instances, the drag increment of the present invention may be less than the viscous friction that would exist on the long flow-control surface which they can replace. This would suggest applications in the aircraft industry where it may be possible to better the drag performance and reduce fuselage tail structure and weight by using the present invention.

In full-scale tests, using a stock 1980 Volkswagon diesel pickup truck, a camper shell was constructed with an array of individual channels 30, as shown in FIG. 2, which commenced at the shell's upper suface immediately behind the truck's roof. The upper surface of the shell was then curved downward 30° over the bed of the truck to terminate at tailgate height. Tufts verified the flow was attached at all surfaces. Despite a severe induced drag penalty due to lift, the C_D fell from the 0.49 of a stock truck and the 0.47 of a commercially available streamlined fiberglass shell to 0.42, allowing the otherwise stock truck to give over 60 mpg in steady state cruise at 55 mph. The unwanted lift and drag increment, which in this case arose from the use of an upper surface for boat-tailing, could have been avoided by simply utilizing flow control surfaces of aerodynamic symmetry, such as the rear fenders 208 and 210, shown in FIGS., 11, 12 and 13.

Although side-by-side cascades of channels have been shown herein, there are some applications where endplates positioned along the streamlines indicated by the arrows 54 or 52 can be used. FIGS. 14 and 15 illustrate such a case wherein a ground effects race car 220 is pictured. Such cars 220 use aerodynamic tunnels 222 and 224 positioned on each side of the driver 226 and the engine 228. Each tunnel has a top surface 230 contoured away from the road surface 232 to generate low static pressures underneath the car 220 between two sidewalls 234 and 236. The top surfaces 230 of the tunnels 222 and 224 act as flow control surfaces which face the road surface 232 and their effect is to improve the tire to road adhesion in much the same manner as also is achieved by the use of inverted airfoils 238 and 240.

The flow through the tunnels 222 and 224 is subject to pressure gradients so severe that heretofore separa-

tion inevitibly occurred near the rear axle 242. This prevented predictable flow from reaching the trailing edge 244 of the tunnel ceiling surface 230, thereby creating a large drag wake and less down-force than was desired requiring the use of the rear auxillary wing 238 with its attendant further increase in drag of the car 220. The vortex generators of the prior art have been tried in the tunnels 222 and 224 in almost every conceivable arrangement with such poor results that they now are seldom seen.

FIGS. 14 and 15 are views of an actual 1/10th scale wind tunnel model of the 1982 Indianapolis Eagle planned to be manufactured by All American Racers, Inc. of Santa Ana, Ca. The model included the channels 92, 94 and 96, shown in FIG. 6, with one cascade 245 in each tunnel 222 and 224, the end plates 234 and 236 acting as outer edge end plates for the cascades 245 and the engine and transmission fairing sidewalls 246 and 248 acting as inner edge end plates. The model of the car 220 was tested with and without the channels 92, 94 and 96. Regardless of the ride height, the model without the channels, 92, 94 and 96 suffered flow separation from the ceilings of the tunnels near the area of the rear axle 242. The flow exited the tunnels in a discrete stream positioned midway between the ground surface and the trailing edge of the tunnels. When the model of the car 220 was equipped with the channels, 92, 94 and 96, tufting and local total head readings showed fully attached flow had been established over the entire lengths of the tunnels 222 and 224. The result was that the downforce increased over 25%, while the downforce to drag ratio was improved 7%, meaning that a car built like the model with less horsepower will be faster both in the corners and on the straightaways if the present invention is included therein.

In FIG. 16, channels 300, 302 and 304 similar to the channels 202, 204 and 206 in FIGS. 11 through 13 are shown applied to modify an existing car 306 whose rear end 308 exists with an unfavorable height 310 so that as the channels 300, 302 and 304 camber around the rear end 308, the floor surface 312 of the last channel 304 must become unacceptably wide. To assure that separation does not occur on the floor 312 a pair of walls 314 and 316, similar to those shown between the dotted lines 317 in FIG. 7, are employed to generate vortices and prevent flow separation adjacent the sides of the license plate area 318 thereof. The effect is the creation of two half channels 320 and 322 like half of channel 96 of FIGS. 6, 7 and 8. The protruberance 324 out of the floor surface 312 formed by the two walls 314 and 316 can be blended into the styling of the car 306 and provides a convenient place to position tail lights 326.

Thus there has been shown and described vortex generating, flow separation preventing channels which can be used in numerous ways to improve the lift and drag characteristics of flow-control surfaces subjected to adverse pressure gradients or to eliminate surface structure otherwise required to avoid adverse pressure gradients, which fulfill all the objects and advantages sought therefore. Many changes, modifications, variations and other uses and applications of the subject channels will become apparent to those skilled in the art after considering this specification and the accompanying drawings. All such changes, modifications, variations and other uses and applications which do not depart from the spirit and scope of the invention are deemed to be covered by the invention which is limited only by the claims which follow.

What is claimed is:

1. Means to maintain flow of a flowing medium attached to the exterior of a flow control member having a flow control surface, said means including:
- a first generally triangularly shaped channel submerged in the flow control surface, said triangularly shaped channel having:
- an apex portion facing the flow of the flowing medium;
- an end portion positioned downstream in the flow of flowing medium from said apex portion;
- a floor surface extending from the flow control surface at said apex portion to said end portion;
- a first sidewall extending between the flow control surface and said floor surface and extending between said apex portion and said end portion, said first sidewall forming a first sidewall edge between said first sidewall and the flow control surface, said first sidewall edge having a forward portion, a rearward portion, and a central portion, said first sidewall central portion being positioned out of alignment with the flow of the flowing medium; and
- a second sidewall extending between the flow control surface and said floor surface and extending between said apex portion and said end portion, said second sidewall forming a second sidewall edge between said second sidewall and the flow control surface, said second sidewall edge having a forward portion, a rearward portion, and a central portion, said second sidewall central portion being positioned out of alignment with the flow of the flowing medium, whereby first and second counterrotating vortices form over said first and second sidewall edges in said first channel which thin the boundry layer of the flow of flowing medium at the adjacent flow control surface and provide turbulent mixing within said first channel so that the flow of flowing medium remains attached to the flow control surface and said floor surface.

2. The means to maintain attached flow as defined in claim 1 further including:
- a first intersection between said first sidewall and said floor surface; and
- a second intersection between said second sidewall and said floor surface, said first and second intersections having local radii not greater than one half the local elevation distance from said floor surface to the flow control surface.

3. The means to maintain attached flow as defined in claim 1 further including:
- a second generally triangularly shaped channel submerged in the flow control surface, said second triangularly shaped channel having:
- a second channel apex portion facing the flow of the flowing medium;
- a second channel end portion positioned downstream in the flow of flowing medium from said second channel apex portion;
- a second channel floor surface extending from the flow control surface at said second channel apex portion to said end portion;
- a second channel first sidewall extending between the flow control surface and said second channel floor surface and extending between said second channel apex portion and said second channel end portion, said second channel first sidewall forming a second

channel first sidewall edge between said second channel first sidewall and the flow control surface, said second channel first sidewall edge having a forward portion, a rearward portion, and a central portion, said second channel first sidewall central portion being positioned out of alignment with the flow of the flowing medium, said second channel first sidewall intersecting said second sidewall of said first channel adjacent said floor surfaces of said first and second channels; and

a second channel second sidewall extending between the flow control surface and said second channel floor surface and extending between said second channel apex portion and said second channel end portion, said second channel second sidewall forming a second channel second sidewall edge between said second channel second sidewall and the flow control surface, said second channel second sidewall edge having a forward portion, a rearward portion, and a central portion, said second channel second sidewall central portion being positioned out of alignment with the flow of the flowing medium, whereby first and second counterrotating vortices form over said second channel first and second sidewall edges in said second channel which thin the boundry layer of the flow of flowing medium at the adjacent flow control surface and provide turbulent mixing within said second channel so that the flow of flowing medium remains attached to the flow control surface and said second channel floor surface.

4. The means to maintain attached flow as defined in claim 1 further including:

a second generally triangularly shaped channel submerged in said floor surface of said first channel, said second triangularly shaped channel having:

a second channel apex portion facing the flow of the flowing medium positioned downstream in the flow of flowing medium from said first channel apex portion;

a second channel end portion positioned downstream in the flow of flowing medium from said first channel end portion;

a second channel floor surface extending from said first channel floor surface at said second channel apex portion to said second channel end portion;

a second channel first sidewall extending between said first channel floor surface and said second channel floor surface and extending between said second channel apex portion and said second channel end portion, said second channel first sidewall forming a second channel first sidewall edge between said second channel first sidewall and said first channel floor surface, said second channel first sidewall edge having a forward portion, a rearward portion, and a central portion, said second channel first sidewall central portion being positioned out of alignment with the flow of the flowing medium; and

a second channel second sidewall extending between said first channel floor surface and said second channel floor surface and extending between said second channel apex portion and said second channel end portion, said second channel second sidewall forming a second channel second sidewall edge between said second channel second sidewall and said first channel floor surface, said second channel second sidewall edge having a forward portion, a rearward portion, and a central portion, said second channel second sidewall central portion being positioned out of alignment with the flow of the flowing medium, whereby third and fourth counterrotating vortices form over said second channel first and second sidewall edges in said second channel which thin the boundry layer of the flow of flowing medium at the adjacent first channel floor surface and provide turbulent mixing within said second channel so that the flow of flowing medium remains attached to said first channel floor surface and said second channel floor surface.

5. The means to maintain attached flow as defined in claim 1 further including:

at least a last generally triangularly shaped channel positioned with respect to said first channel so that a plurality of similiar submerged generally triangularly shaped channels are formed in series from upstream to downstream in the flow of flowing medium and in the flow control surface, said last triangularly shaped channel having:

a last channel apex portion facing the flow of the flowing medium positioned downstream in the flow of flowing medium from said upstream adjacent channel apex portion;

a last channel end portion positioned downstream in the flow of flowing medium from said upstream adjacent channel end portion;

a last channel floor surface extending from said upstream adjacent channel floor surface at said last channel apex portion to said last channel end portion;

a last channel first sidewall extending between said upstream adjacent channel floor surface and said last channel floor surface and extending between said last channel apex portion and said last channel end portion, said last channel first sidewall forming a last channel first sidewall edge between said last channel first sidewall and said upstream adjacent channel floor surface, said last channel first sidewall edge having a forward portion, a rearward portion, and a central portion, said last channel first sidewall central portion being positioned out of alignment with the flow of the flowing medium; and

a last channel second sidewall extending between said upstream adjacent channel floor surface and said last channel floor surface and extending between said last channel apex portion and said last channel end portion, said last channel second sidewall forming a last channel second sidewall edge between said last channel second sidewall and said upstream adjacent channel floor surface, said last channel second sidewall edge having a forward portion, a rearward portion, and a central portion, said last channel second sidewall central portion being positioned out of alignment with the flow of the flowing medium, whereby third and fourth counterrotating vortices form over said last channel first and second sidewall edges in said last channel which thin the boundry layer of the flow of flowing medium at the adjacent upstream adjacent channel floor surface and provide turbulent mixing within said last channel so that the flow of flowing medium remains

attached to said upstream adjacent channel floor surface and said last channel floor surface.

6. The means to maintain attached flow as defined in claim 5 wherein the flow control surface has a trailing edge, said last channel second sidewall extending to the trailing edge of the flow control surface.

7. The means to maintain attached flow as defined in claim 6 wherein said last channel first sidewall extends to the trailing edge of the flow control surface.

8. The means to maintain attached flow as defined in claim 6 including:

a second series of said channels similiar to said first series of channels positioned with said last channel second sidewall of said first series intersecting said last channel first sidewall of said second series.

9. The means to maintain attached flow as defined in claim 5 wherein said last channel floor surface includes:

a first generally triangularly shaped protrusion extending from said last channel floor surface, said generally triangularly shaped protrusion having:

a front portion facing the flow of the flowing medium;

an apex portion positioned downstream in the flow of flowing medium from said front portion;

a top surface extending from said last channel floor surface at said to said apex portion;

a first sidewall extending between said last channel floor surface and said top surface and extending between said front portion and said apex portion, said first sidewall forming a first sidewall edge between said first sidewall and said top surface, at least a portion of said first sidewall being positioned at an angle to the flow of the flowing medium; and

a second sidewall extending between said last channel floor surface and said top surface and extending between said front portion and said apex portion, said second sidewall forming a second sidewall edge between said second sidewall and said top surface, at least a portion of said second sidewall being positioned at an angle to the flow of the flowing medium, whereby fifth and sixth counterrotating vortices form over said first and second sidewall edges of said first generally triangularly shaped protrusion which thin the boundry layer of the flow of flowing medium at the adjacent top surface and provide turbulent mixing within said last channel so that the flow of flowing medium remains attached.

10. The means to maintain attached flow as defined in claim 1 wherein said first floor surface extends upwardly to intersect with the flow control surface adjacent said rear portion of said second sidewall edge.

11. The means to maintain attached flow as defined in claim 10 further including:

at least a last generally triangularly shaped channel positioned with respect to said first channel so that a plurality of similiar submerged generally triangularly shaped channels are formed in a first series from upstream to downstream in the flow of flowing medium and in the flow control surface, said last triangularly shaped channel having:

a last channel apex portion facing the flow of the flowing medium positioned downstream in the flow of flowing medium from said upstream adjacent channel apex portion;

a last channel end portion positioned downstream in the flow of flowing medium from said upstream adjacent channel end portion;

a last channel floor surface extending from said upstream adjacent channel floor surface at said last channel apex portion to said last channel end portion submerged from the flow control surface;

a last channel first sidewall extending between said upstream adjacent channel floor surface and said last channel floor surface and extending between said last channel apex portion and said last channel end portion, said last channel first sidewall forming a last channel first sidewall edge between said last channel first sidewall and said upstream adjacent channel floor surface, said last channel first sidewall edge having a forward portion, a rearward portion, and a central portion, said last channel first sidewall central portion being positioned out of alignment with the flow of the flowing medium; and

a last channel second sidewall extending between said upstream adjacent channel floor surface and said last channel floor surface and extending between said last channel apex portion and said last channel end portion, said last channel second sidewall forming a last channel second sidewall edge between said last channel second sidewall and said upstream adjacent channel floor surface, said last channel second sidewall edge having a forward portion, a rearward portion, and a central portion, said last channel second sidewall central portion being positioned out of alignment with the flow of the flowing medium, whereby third and fourth counterrotating vortices form over said last channel first and second sidewall edges in said last channel which thin the boundry layer of the flow of flowing medium at the adjacent upstream adjacent channel floor surface and provide turbulent mixing within said last channel so that the flow of flowing medium remains attached to said upstream adjacent channel floor surface and said last channel floor surface.

12. The means to maintain attached flow as defined in claim 11 wherein the flow control surface has a trailing edge, said last channel second sidewall extending to the trailing edge of the flow control surface.

13. The means to maintain attached flow as defined in claim 12 including:

a second series of said channels similiar to said first series of channels positioned with said last channel second sidewall of said first series intersecting said last channel first sidewall of said second series.

14. The means to maintain attached flow as defined in claim 10 further including:

at least a last generally triangularly shaped channel positioned with respect to said first channel so that a plurality of similiar submerged generally triangularly shaped channels are formed in a first series from upstream to downstream in the flow of flowing medium and in the flow control surface, said last triangularly shaped channel having:

a last channel apex portion facing the flow of the flowing medium positioned downstream in the flow of flowing medium from said upstream adjacent channel apex portion;

a last channel end portion positioned downstream in the flow of flowing medium from said upstream adjacent channel end portion;

a last channel floor surface extending from said upstream adjacent channel floor surface at said last channel apex portion to said last channel end portion at a point of intersection to the flow control surface;

a last channel first sidewall extending between said upstream adjacent channel floor surface and said last channel floor surface and extending between said last channel apex portion and said last channel end portion, said last channel first sidewall forming a last channel first sidewall edge between said last channel first sidewall and said upstream adjacent channel floor surface, said last channel first sidewall edge having a forward portion, a rearward portion, and a central portion, said last channel first sidewall central portion being positioned out of alignment with the flow of the flowing medium; and

a last channel second sidewall extending between said upstream adjacent channel floor surface and said last channel floor surface and extending between said last channel apex portion and said last channel end portion, said last channel second sidewall forming a last channel second sidewall edge between said last channel second sidewall and said upstream adjacent channel floor surface, said last channel second sidewall edge having a forward portion, a rearward portion, and a central portion, said last channel second sidewall central portion being positioned out of alignment with the flow of the flowing medium, whereby third and fourth counterrotating vortices form over said last channel first and second sidewall edges in said last channel which thin the boundry layer of the flow of flowing medium at the adjacent upstream adjacent channel floor surface and provide turbulent mixing within said last channel so that the flow of flowing medium remains attached to said upstream adjacent channel floor surface and said last channel floor surface.

15. The means to maintain attached flow as defined in claim 14 wherein at least a portion of said first channel floor surface is positioned at an acute angle with respect the adjacent sidewall.

16. The means to maintain attached flow as defined in claim 1 wherein said first and second sidewall edges are relatively sharp edges.

17. The means to maintain attached flow as defined in claim 1 wherein said first and second sidewall edges form an ogee shape with the flow control surface.

18. The means to maintain attached flow as defined in claim 17 wherein said ogee shape of said first and second sidewall edges is so shaped as to maintain an angle of attack to the local flow of the flowing medium thereover at least at said central portions thereof.

19. The means to maintain attached flow as defined in claim 1 wherein said first channel includes:

a third sidewall extending from said first channel floor surface generally facing said first sidewall;

a fourth sidewall extending from said first channel floor surface generally facing said second sidewall and intersecting said third sidewall adjacent said first channel end portion; and

a roof surface extending from said first channel floor surface to said end portion of said first channel between said third and fourth sidewalls and forming third and fourth sidewall edges therewith, at least portions of which are positioned at an angle of attack with the local flow of the flowing medium whereby a series/parallel arrangement of at least three channels is formed.

20. The means to maintain attached flow as defined in claim 1 wherein said first and second sidewall edges extend above the adjacent flow control surface.

21. Means to maintain flow of a flowing medium attached to the exterior of a flow control member having a flow control surface by thinning the boundry layer thereof, said means including:

a first channel formed in the flow control surface, said first channel having:

a forward portion generally facing the flow of the flowing medium;

an end portion positioned downstream in the flow of flowing medium from said forward portion;

a floor surface extending from the flow control surface at said forward portion to said end portion; and

a first sidewall extending between the flow control surface and said floor surface and extending between said forward portion and said end portion, said first sidewall forming a first sidewall edge between said first sidewall and the flow control surface, said first sidewall edge having a forward portion, a rearward portion, and a central portion, said first sidewall central portion being positioned out of alignment with the flow of the flowing medium, whereby a first counterrotating vortex forms over said first sidewall edge in said first channel which thins the boundry layer of the flow of flowing medium at the adjacent flow control surface and provides turbulent mixing within said first channel so that the flow of flowing medium remains attached to the flow control surface and said floor surface.

22. The means to maintain attached flow as defined in claim 21 further including:

at least a last channel positioned with respect to said first channel so that a plurality of similiar submerged channels are formed in series from upstream to downstream in the flow of flowing medium and in the flow control surface, said last channel having:

a last channel forward portion generally facing the flow of the flowing medium positioned downstream in the flow of flowing medium from said upstream adjacent channel forward portion;

a last channel end portion positioned downstream in the flow of flowing medium from said upstream adjacent channel end portion;

a last channel floor surface extending from said upstream adjacent channel floor surface at said last channel forward portion to said last channel end portion; and

a last channel first sidewall extending between said upstream adjacent channel floor surface and said last channel floor surface and extending between said last channel forward portion and said last channel end portion, said last channel first sidewall forming a last channel first sidewall edge between said last channel first sidewall and said upstream adjacent channel floor surface, said last channel first sidewall edge having a forward portion, a rearward portion, and a central por-

tion, said last channel first sidewall central portion being positioned out of alignment with the flow of the flowing medium, whereby a second counterrotating vortex forms over said last channel first edge in said last channel which thins the boundry layer of the flow of flowing medium at the adjacent upstream adjacent channel floor surface and provides turbulent mixing within said last channel so that the flow of flowing medium remains attached to said upstream adjacent channel floor surface and said last channel floor surface.

23. The means to maintain attached flow as defined in claim 22 further including:

a fence bounding the flow control surface generally parallel to said first and last channels, said first sidewalls and said floor surfaces of said first and last channels intersecting said fence at said end portions thereof.

24. The means to maintain attached flow as defined in claim 22 further including:

a fence bounding the flow control surface generally parallel to said first and last channels, said floor surfaces of said first and last channels intersecting said fence at said end portions thereof.

25. The means to maintain attached flow as defined in claim 22 wherein the flow control surface has a trailing edge, said last channel first sidewall extending to the trailing edge of the flow control surface.

26. The means to maintain attached flow as defined in claim 25 including:

a second series of said channels similiar and sidewardly reversed to said first series of channels positioned with said last channel first sidewall of said first series intersecting said last channel first sidewall of said second series.

27. The means to maintain attached flow as defined in claim 21 further including:

at least a last channel positioned with respect to said first channel so that a plurality of similiar submerged channels are formed in a first series from upstream to downstream in the flow of flowing medium and in the flow control surface, said last having:

a last channel forward portion generally facing the flow of the flowing medium positioned downstream in the flow of flowing medium from said upstream adjacent channel forward portion;

a last channel end portion positioned downstream in the flow of flowing medium from said upstream adjacent channel end portion;

a last channel floor surface extending from said upstream adjacent channel floor surface at said last channel forward portion to said last channel end portion submerged from the flow control surface; and

a last channel first sidewall extending between said upstream adjacent channel floor surface and said last channel floor surface and extending between said last channel forward portion and said last channel end portion, said last channel first sidewall forming a last channel first sidewall edge between said last channel first sidewall and said upstream adjacent channel floor surface, said last channel first sidewall edge having a forward portion, a rearward portion, and a central portion, said last channel first sidewall central portion being positioned out of alignment with the flow of the flowing medium, whereby a second counterrotating vortex forms over said last channel first sidewall edge in said last channel which thins the boundry layer of the flow of flowing medium at the adjacent upstream adjacent channel floor surface and provides turbulent mixing within said last channel so that the flow of flowing medium remains attached to said upstream adjacent channel floor surface and said last channel floor surface.

28. The means to maintain attached flow as defined in claim 27 wherein the flow control surface has a trailing edge, said last channel first sidewall extending to the trailing edge of the flow control surface.

29. The means to maintain attached flow as defined in claim 28 including:

a second series of channels similiar and sidewardly reversed to said first series of channels positioned with said last channel first sidewall of said first series of channels intersecting said last channel first sidewall of said second series of channels.

30. The means to maintain attached flow as defined in claim 21 wherein said first floor surface extends upwardly to intersection with the flow control surface at said forward portion, said means to maintain attached flow further including:

at least a last channel positioned with respect to said first channel so that a plurality of similiar submerged channels are formed in a first series from upstream to downstream in the flow of flowing medium and in the flow control surface, said last channel having:

a last channel forward portion generally facing the flow of the flowing medium positioned downstream in the flow of flowing medium from said upstream adjacent channel forward portion;

a last channel end portion positioned downstream in the flow of flowing medium from said upstream adjacent channel end portion;

a last channel floor surface extending from said upstream adjacent channel floor surface at said last channel forward portion to said last channel end portion at a point of intersection with the flow control surface; and

a last channel first sidewall extending between said upstream adjacent channel floor surface and said last channel floor surface and extending between said last channel forward portion and said last channel end portion, said last channel first sidewall forming a last channel first sidewall edge between said last channel first sidewall and said upstream adjacent channel floor surface, at least a portion of said last channel first sidewall edge being positioned at an angle to the flow of the flowing medium, whereby a second counterrotating vortex forms over said last channel first sidewall edge in said last channel which thins the boundry layer of the flow of flowing medium at the adjacent upstream adjacent channel floor surface and provides turbulent mixing within said last channel so that the flow of flowing medium remains attached to said upstream adjacent channel floor surface and said last channel floor surface.

31. The mean maintain attached flow as defined in claim 30 including:

a fence bounding the flow control surface generally parallel to said first and last channels, said floor

surfaces of at least said first channel intersecting said fence at said end portions thereof.

32. The means to maintain attached flow as defined in claim 21 wherein said first flow surface extends upwardly to intersection with the flow control surface at said forward portion and said end portion of said first channel.

33. The means to maintain attached flow as defined in claim 21 wherein said first sidewall edge forms an ogee shape with the flow control surface, said ogee shape being so shaped as to maintain an angle of attack to the local flow of the flowing medium thereover at least at said central portion thereof.

34. The means to maintain attached flow as defined in claim 21 wherein at least a portion of said floor surface is positioned at an acute angle with respect to said first side wall.

35. The means to maintain attached flow as defined in claim 21 wherein said first channel includes:

a second sidewall extending from said first channel floor surface generally facing said first sidewall;

a third sidewall extending from said first channel floor surface generally facing away from said first sidewall and intersecting said second sidewall adjacent said first channel end portion; and

a roof surface extending from said first channel floor surface to said end portion of said first channel between said second and third sidewalls and forming second and third sidewall edges therewith, at least portions of which are positioned at an angle of attack with the local flow of the flowing medium whereby a series/parallel arrangement of channels is formed.

36. The means to maintain attached flow as defined in claim 21 wherein said first channel includes:

a fence bounding the flow control surface generally parallel to said first channel, said first sidewall intersecting said fence at said end portion.

37. A body having a usual direction of motion through a medium, a front, a rear, and rear side areas which rear side areas each include:

a flow control surface;

a first channel formed in said flow control surface, said first channel having:

a forward portion generally facing the front;

an end portion positioned closer to the rear than said forward portion;

a floor surface extending from said flow control surface at said forward portion to said end portion; and

a first sidewall extending between said flow control surface and said floor surface and extending between said forward portion and said end portion, said first sidewall forming a first sidewall edge between said first sidewall and said flow control surface, said first sidewall edge having at least a portion positioned out of alignment with the usual direction of motion of said body; and

a last channel formed in said flow control surface, said last channel having:

a forward portion generally facing the front;

an end portion positioned closer to the rear than said forward portion of said last channel;

a floor surface extending from said flow control surface at said last channel forward portion to said last channel end portion; and

a first sidewall extending between said flow control surface and said last channel floor surface and extending between said last channel forward portion and said last channel end portion, said last channel first sidewall forming a last channel first sidewall edge between said last channel first sidewall and said flow control surface, said last channel first sidewall edge having at least a portion positioned out of alignment with the usual direction of motion of said body.

38. The body defined in claim 37 wherein said first channel further includes:

a second sidewall extending between said flow control surface and said floor surface and extending between said forward portion and said end portion, said second sidewall forming a second sidewall edge between said second sidewall and said flow control surface, said second sidewall edge having at least a portion positioned out of alignment with the usual direction of motion of said body.

39. The body defined in claim 38 wherein said last channel further includes:

a second sidewall extending between said flow control surface and said last channel floor surface and extending between said last channel forward portion and said last channel end portion, said last channel second sidewall forming a last channel second sidewall edge between said last channel second sidewall and said flow control surface, said last channel second sidewall edge having at least a portion positioned out of alignment with the usual direction of motion of said body.

40. A motor vehicle having a usual direction of motion, said body including a front, a rear, and right and left rear fender areas, said rear fender areas each having a flow control surface, and means to maintain flow of the medium attached to the exterior of said rear fender areas having said flow control surface, said means including:

a first channel formed in each said fender surface, said first channel having:

a forward portion generally facing the front;

an end portion positioned closer to the rear than said forward portion;

a floor surface extending from said fender surface at said forward portion to said end portion; and

a first sidewall extending between said fender surface and said floor surface and extending between said forward portion and said end portion, said first sidewall forming a firt sidewall edge between said first sidewall and said fender surface, said first sidewall edge having at least a portion positioned out of alignment with the usual direction of motion of said motor vehicle.

41. The motor vehicle defined in claim 40 wherein said first channel further includes:

a second sidewall extending between said fender surface and said floor surface and extending between said forward portion and said end portion, said second sidewall forming a second sidewall edge between said second sidewall and said fender surface, said second sidewall edge having at least a portion positioned out of alignment with the usual direction of motion of said motor vehicle.

42. The motor vehicle defined in claim 40 further including:

a last channel formed in said fender surface, said last channel having:

a forward portion generally facing the front;

an end portion positioned closer to the rear than said forward portion of said last channel;

a floor surface extending from said fender surface at said last channel forward portion to said last channel end portion; and

a first sidewall extending between said fender surface and said last channel floor surface and extending between said last channel forward portion and said last channel end portion, said last channel first sidewall forming a last channel first sidewall edge between said last channel first sidewall and said fender surface, said last channel first sidewall edge having at least a portion positioned out of alignment with the usual direction of motion of said motor vehicle.

43. The motor vehicle defined in claim 42 wherein said last channel further includes:

a second sidewall extending between said fender surface and said last channel floor surface and extending between said last channel forward portion and said last channel end portion, said last channel second sidewall forming a last channel second sidewall edge between said last channel second sidewall and said fender surface, said last channel second sidewall edge having at least a portion positioned out of alignment with the usual direction of motion of said motor vehicle.

44. The motor vehicle defined in claim 42 further including:

a rear area connecting said floor surfaces of said last channels in said right and left fender areas.

45. The motor vehicle defined in claim 44 wherein said rear area includes a cusp portion pointing opposite from the usual direction of motion of said motor vehicle.

46. The means to maintain attached flow as defined in claim 40 wherein said last channel includes a protrusion formed by:

a second sidewall extending from said last channel floor surface generally facing said first sidewall;

a third sidewall extending from said last channel floor surface generally facing away from said first sidewall and intersecting said second sidewall adjacent said last channel end portion; and

a roof surface extending from said last channel floor surface to said end portion of said last channel between said second and third sidewalls and forming second and third sidewall edges therewith, at least portions of which are positioned at an angle of attack with the local flow of the flowing medium whereby a series/parallel arrangement of channels is formed.

47. The means to maintain attached flow as defined in claim 46 wherein said protrusion includes a tail light assembly positioned near said last channel end portion.

48. An automobile having a usual direction of motion, a front, a rear, and right and left rear downforce creating tunnels generally aligned with the usual direction of motion, each rear downforce creating tunnels including:

an upper undersurface; and

a first channel formed in said upper undersurface, said first channel having:

a forward portion generally facing the front;

an end portion positioned closer to the rear than said forward portion;

a floor surface extending from said upper undersurface at said forward portion to said end portion;

a first sidewall extending between said upper undersurface and said floor surface and extending between said forward portion and said end portion, said first sidewall forming a first sidewall edge between said first sidewall and said upper undersurface, said first sidewall edge having at least a portion positioned out of longitudinal alignment with said tunnel; and

a second sidewall extending between said upper undersurface and said floor surface and extending between said forward portion and said end portion, said second sidewall forming a second sidewall edge between said second sidewall and said upper undersurface, said second sidewall edge having at least a portion positioned out of longitudinal alignment with said tunnel.

49. The automobile as defined in claim 48 further including:

a last channel formed in said upper undersurface, said last channel having:

a forward portion generally facing the front;

an end portion positioned closer to the rear than said last channel forward portion;

a floor surface extending from said upper undersurface at said last channel forward portion to said last channel end portion;

a first sidewall extending between said floor surface of said first channel and said last channel floor surface and extending between said last channel forward portion and said last channel end portion, said last channel first sidewall forming a last channel first sidewall edge between said last channel first sidewall and said floor surface of said first channel, said last channel first sidewall edge having at least a portion positioned out of longitudinal alignment with said tunnel; and

a second sidewall extending between said floor surface of said first channel and said last channel floor surface and extending between said last channel forward portion and said last channel end portion, said last channel second sidewall forming a last channel second sidewall edge between said last channel second sidewall and said floor surface of said first channel, said last channel second sidewall edge having at least a portion positioned out of longitudinal alignment with said tunnel.

50. The automobile as defined in claim 48 wherein each of said tunnels includes:

a fence bounding said upper surface generally parallel to said first channel, said first sidewall intersecting said fence at said end portion.

51. The means to maintain attached flow as defined in claim 48 wherein said first channel includes:

a fence bounding said upper surface generally parallel to said first channel, said floor surface intersecting said fence at said end portion.

52. The means to maintain attached flow as defined in claim 49 further including:

a fence bounding said upper surface generally parallel to said first and last channels, said first sidewalls and said floor surfaces of said first and last channels intersecting said fence at said end portions thereof.

53. The means to maintain attached flow as defined in claim 49 further including:

a fence bounding the flow control surface generally parallel to said first and last channels, said floor surfaces of said first and last channels intersecting said fence at said end portions thereof.

* * * * *

United States Patent [19]

Slemmons

[11] **Patent Number: 4,825,795**

[45] **Date of Patent: May 2, 1989**

[54] **SAILING CRAFT KEEL AND RUDDER FLOW MODIFIERS**

[76] Inventor: **Arthur J. Slemmons, 19655 Redberry Dr., Los Gatos, Calif. 95030**

[21] Appl. No.: **28,100**

[22] Filed: **Mar. 19, 1987**

[51] Int. Cl.[4] **B63B 3/38**

[52] U.S. Cl. .... **114/140**; 114/67 R; 114/162

[58] **Field of Search** .... 114/39.1, 39.2, 61, 114/123, 127, 140, 141, 142, 143, 162, 270, 67 R; 244/199, 200

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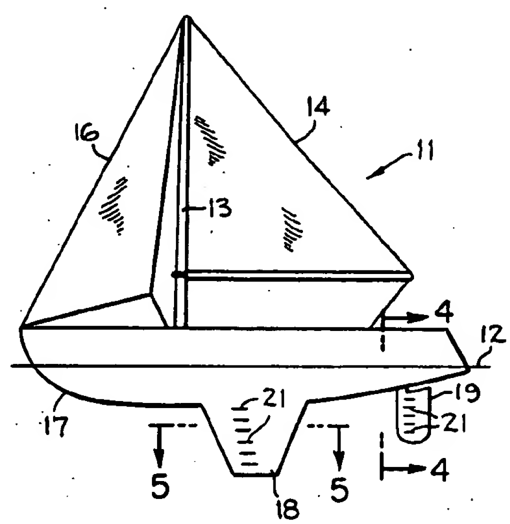
Primary Examiner—Sherman D. Basinger
Assistant Examiner—Stephen P. Avila
Attorney, Agent, or Firm—Henry M. Stanley

[57] **ABSTRACT**

Arrays of parallel, substantially fore and aft oriented vortex generators are positioned on the keel and rudder of a sailboat to induce vortices at the surfaces of the keel and rudder for the purpose of reenergizing the boundary layers in the water flow past the keel and the rudder to increase the lateral lift in the horizontal plane and to thereby avoid increase in drag associated with keel and rudder stall at high angles of attack with the relative water flow. Similar arrays for the same purpose may be attached to other underwater stabilizing members such as skegs, keel winglets, centerboards, etc.

16 Claims, 2 Drawing Sheets



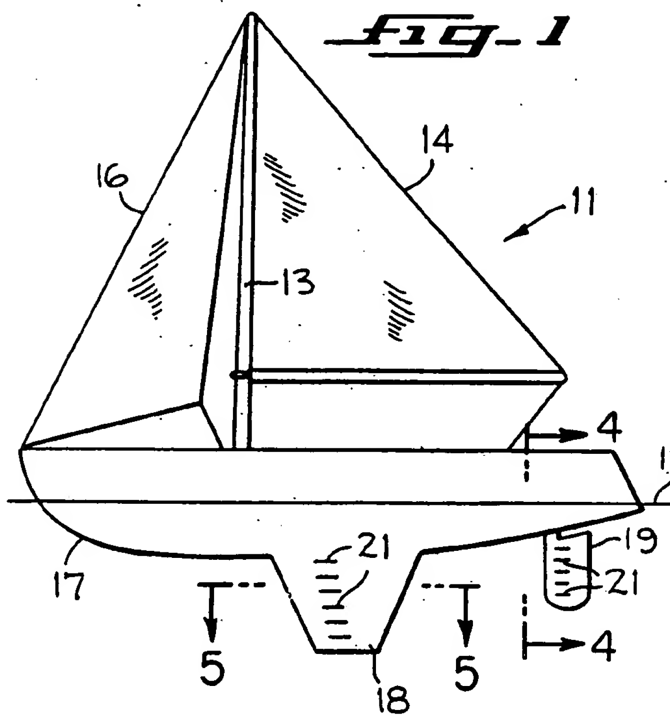


fig. 1

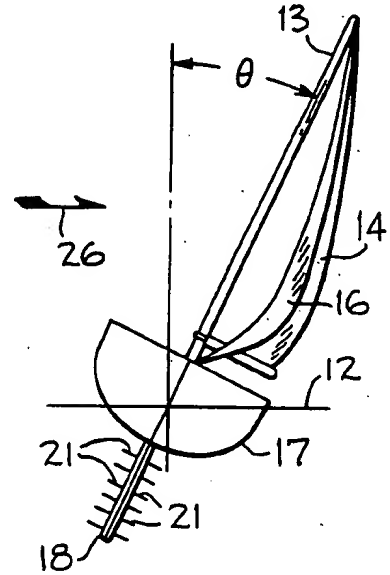


fig. 2

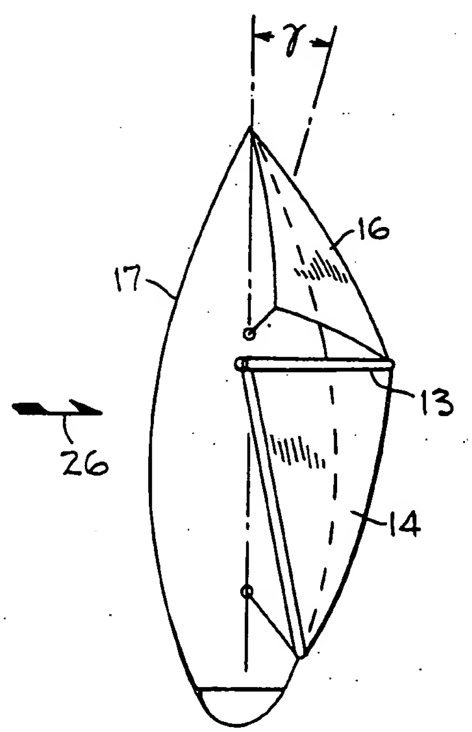


fig. 3

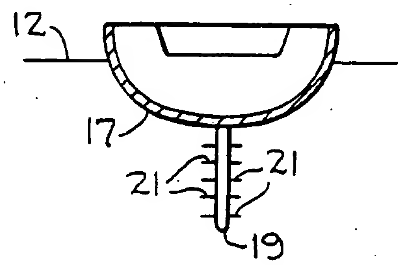


fig. 4

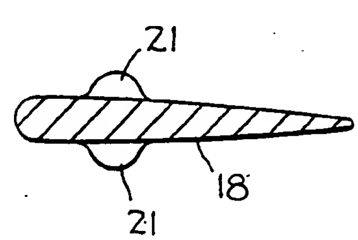


fig. 5

FIG. 6

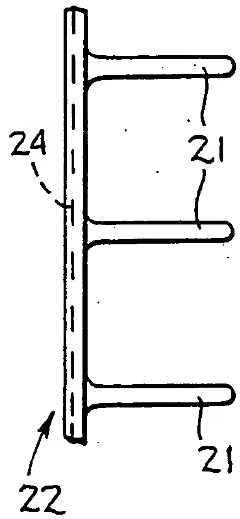


FIG. 7

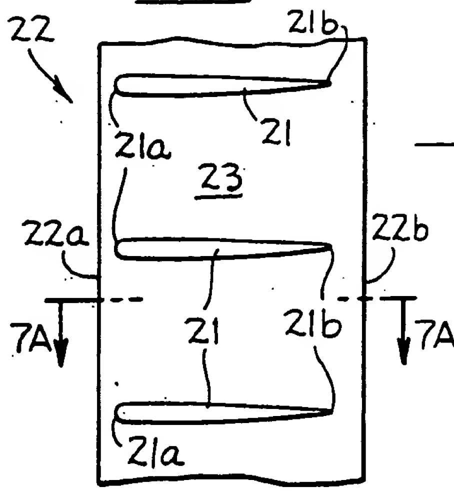
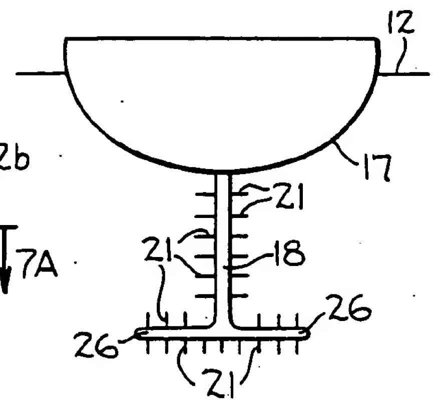


FIG. 8



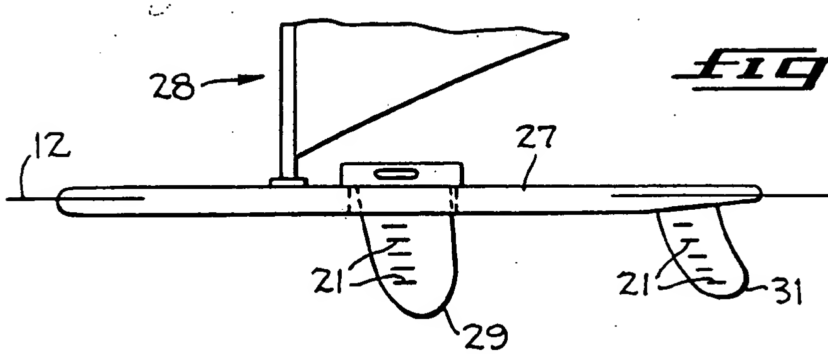


FIG. 9

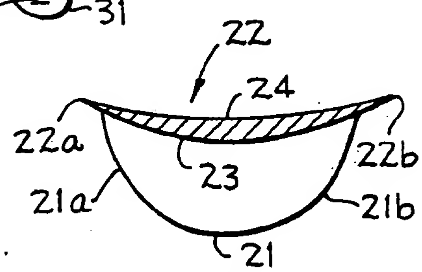


FIG. 7A

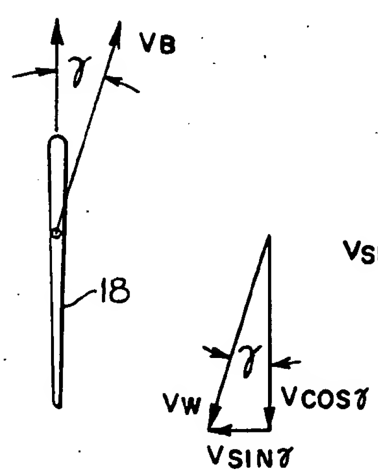


FIG. 10

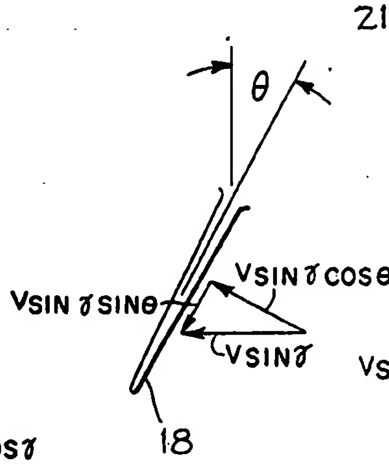
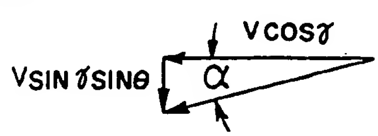


FIG. 11

FIG. 12



SAILING CRAFT KEEL AND RUDDER FLOW MODIFIERS

BACKGROUND OF THE INVENTION

I. Field of the Invention

This invention relates to flow modifiers for sailboat keels and rudders and more particularly to vortex generators for application to sailboat keels and rudders to achieve boundary layer control.

II. Description of the Prior Art

From 1948 through 1950, H. D. Taylor of the United Aircraft Corporation discovered that small mixing devices, now known as vortex generators can be used to increase the efficiency of diverging wall diffusers, air foils, axial flow fans, burner mixing, etc. The generators are simply energy converters in the form of an array of small, closely spaced, low aspect ratio foils or tabs mounted at an angle of attack to the free air stream on a surface having a boundary layer. Each generator accomplishes a conversion of translational energy into rotational energy in the form of a trailing tip vortex. The induced tip vortices reenergize the boundary layer by mixing the higher velocity air in the main stream with the lower velocity air in the boundary layer. This reenergizing of the boundary layer makes it more resistant to separation from a surface with an adverse pressure gradient. Separation would otherwise result in a leveling off of lift and large increases in drag with increasing air foil angles of attack. This is called stall and results in a loss of efficiency commonly measured as lift/drag (L/D) ratio.

Common applications of this principle are on axial flow fan intake shrouds, diverging diffusers, windmill blades, airplane wings and airplane vertical and horizontal stabilizers. The greatest number of applications have been on airplane wings. The vortex generators are placed on the wing surface at an angle of attack to the fore and aft direction of airplane travel. The foil axes of the vortex generators are either in an alternating plus and minus angle of attack orientation relative to the direction of the airplane travel to generate adjacent counter-rotating vortices, or in a parallel array with the foil axes at a constant angle of attack to the fore and aft direction of the airplane to generate co-rotating trailing vortices.

Due to the angle of attack of the vortex generators relative to the forward motion of the airplane, there is a small drag penalty for using vortex generators on aircraft surfaces at angles of attack which are less than the angle at which wing or control surfaces normally stall. This small drag penalty during normal flight is accepted in order to avoid the large losses in lift and much larger increases in drag during transient conditions requiring larger lift coefficients at higher angles of attack, beyond which, without the vortex generators, such surfaces would otherwise experience stall. The use of vortex generators allows the use of a smaller wing on an aircraft. Consequently, the smaller wing may be brought to a higher angle of attack producing higher lift before stall occurs. Thus, the large drag increase that occurs at stall is delayed until higher angles of attack occur. A relatively complete discussion of boundary layer control and vortex generators is found in Chapter VI of *Incompressible Aerodynamics*, Bryan Thwaites, published 1960, Oxford at the Clarendon Press.

The only known prior art in sailboats or marine vehicles using any type of foil on keels and rudders have been large lifting foils. These have generally been dimensionally large and used to lift the boat vertically out of the water. To develop such lift the foils are mounted with their foil axes at angles of attack to the fore and aft direction of the boat. The flow caused by the boat's forward motion through the water causes these foils to develop an upwards lift on the boat. Such arrangements are seen in U.S. Pat. No. 4,599,964, Kenny et al, and U.S. Pat. No. 4,606,291, Karl-Gunther W. Hoppe.

SUMMARY OF THE INVENTION

In one aspect of the invention disclosed herein a sailboat keel has opposing surfaces with a vertical span and a fore and aft extending chord. A plurality of spaced vortex generators are aligned in a row in the direction of the span, each generator extending laterally from the keel and aligned substantially with the chord. The plurality of vortex generators includes a continuous strip adapted for attachment to the keel surface with a plurality of vortex generator extending from the strip.

In another aspect of the invention a depending stabilizing member has a span extending from the underside of a sail equipped vessel which is adapted for wind driven movement across a water surface. An array of spaced foils are attached to and extend laterally from the stabilizing member along at least a portion of the span thereof. The spaced vortex generators are formed on a strip extending in the span direction with a plurality of integral foils spaced along and extending outwardly from the strip.

In yet another aspect of the invention apparatus is disclosed for inducing vortices in a flowing fluid. The apparatus includes a strip having opposing edges and a concave surface on one side of the strip with a convex surface on the opposing side of the strip. The convex and concave sides of the strip intersect at an least one edge of the strip so that they form a sharp edge along the length of the strip. A plurality of integral vortex generators are arrayed along the length of the strip extending between the edges thereof.

In yet another aspect of the invention apparatus is disclosed for inducing vortices in an incompressible fluid flow. A strip has a forward edge and a trailing edge and an upper and an under surface. The upper and under surfaces intersect at an acute angle at the forward edge of the strip and a plurality of vortex generating foils extends from the upper surface of the strip and between the forward and trailing edges thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevation view of a sailboat incorporating the present invention.

FIG. 2 is a bow view of a sailboat incorporating the present invention and heeled at an angle theta.

FIG. 3 is a plan view of the sailboat of FIG. 2.

FIG. 4 is a section along the line 4—4 of FIG. 1.

FIG. 5 is a section along the line 5—5 of FIG. 1.

FIG. 6 is a partial front view of a strip having an array of vortex generators formed thereon.

FIG. 7 is a plan view of the array of FIG. 6.

FIG. 7A is a section along the line 7A—7A of FIG. 7.

FIG. 8 is a bow view of a sailboat hull and keel incorporating the present invention.

FIG. 9 is an elevation view of a sail board incorporating the present invention.

FIG. 10 is a vector diagram showing water velocity relative to a sailboat keel.

FIG. 11 is a vector diagram showing another component of water velocity relative to a sailboat keel.

FIG. 12 is a vector diagram derived from FIGS. 10 and 11 showing the angle of attack of water at a vortex generator of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Sailboat keels and rudders are used for horizontal upwind "lift" and steering in the water in the same manner as wings and movable control surfaces are used for vertical lift in aircraft moving through the air. The same basic scientific principles of fluid dynamics apply in both cases. In the case of aircraft the fluid is air, and in the case of sailboats the fluid is water. Boundary layer control has been found to be advantageous to delay stall in sailboat keel and rudder foils immersed in water. The maintenance of high horizontal lift coefficients and low drag coefficients (high L/D ratios) for sailboat keels and rudders is essential to the sailboat's speed through the water. The disclosed invention relates to the use of vortex generators that provide boundary layer control for sailboat keels and rudders and the like and yet avoid the drag penalty that would result from using vortex generators if the vortex generator foils were oriented at an angle to the fore and aft direction of the boat. This result is obtained due to a unique situation which is peculiar to sailboat keels and rudders and is utilized to achieve the aforementioned desirable objective.

As seen in FIG. 1 a sailboat shown generally at 11 is supported on the surface of a body of water 12 by buoyant force. The sailboat has a mast 13 which supports a mainsail 14 and a foresail 16. The sail rigging is of the usual type and is not described here as it is not pertinent to the disclosed invention. The sailboat has a hull 17 with stabilizing members depending from the underside thereof such as a keel 18 and a rudder 19. The keel and the rudder may be seen to extend a certain distance beneath the hull, which will be referred to as the span of the stabilizing member. In like fashion, each stabilizing member has a width from fore to aft which will be referred to as the chord. As seen in FIG. 1 an array of vortex generators or foils 21 extends in the direction of the span of the keel or rudder. FIG. 5 shows the manner in which the individual foils extend laterally from the stabilizing member (the keel in this instance). The vortex generators are generally short in span (root to tip) compared to their chord (leading rounded edge to trailing tapered edge). The ratio of span to chord is called the aspect ratio. The vortex generators of this invention preferably have a low aspect ratio. The vortex generators have a rounded shape in the plan view of FIG. 5, although triangular, rectangular or other shapes may serve as well.

FIGS. 6, 7 and 7A show a strip 22 having a plurality of spaced vortex generators 21 integrally formed with the strip and extending from an upper convex surface 23 on the strip as indicated in FIG. 7. Fillets are formed as shown between the vortex generator surfaces and the convex surface 23. The under surface of the strip is concave as indicated by the hidden line 24 in FIG. 6 and as shown in FIG. 7A. The vortex generators 21 are preferably rounded at a forward edge 21*a* and tapered to a thinner trailing edge 21*b* as best seen in FIG. 7. The strip thus has a forward edge 22*a* and a trailing edge 22*b* as also best seen in FIG. 7. It is important for the upper convex surface 23 to intersect the lower concave surface 24 of the strip 22 at an acute angle so that the forward edge 22*a* of the strip is feathered to a sharp configuration as shown in exaggerated fashion in FIG. 7A. It is preferred that the trailing edge 22*b* of the strip have a similar configuration as also shown in FIG. 7A. In this fashion when the strip 22 is fastened, for example by an adhesive, to the surface of a keel 18 or rudder 19, any irregularities in the keel or rudder surface do not distort the strip and the orientation of the vortex generators 21. Further, as applied to the stabilizing member the forward sharp edge 22*a* (at least) of the strip is faired into the keel or rudder surface as seen in FIG. 5. In like fashion, in the preferred form the trailing edge 22*b* of the strip is also faired into the surface of the stabilizing keel or rudder member.

The unique situation to which reference was made hereinbefore relates to the fact that when the sailboat is in lightwind conditions or is going downwind in a straight line there is relatively little lateral force on the boat, keel or rudder and there is little tendency for the keel or rudder to stall. The mast remains almost vertical and the flow of the water relative to the keel is essentially parallel, horizontal and to the rear. Consequently, vortex generators 21 arrayed as seen in FIG. 1 or FIG. 4 will have substantially zero angle of attack to the water flow and will therefore induce little or no additional drag. The amount of additional drag due to frontal area and additional wetted surface of the vortex generators is nearly negligible. When the sailboat is sailing crosswind or upwind, or is on a broad reach, however, there can be large lateral forces on the keel and rudder as the hull 17 rolls sideways or "heels". These large lateral forces are derived from the wind forces represented by the arrow 26 in FIGS. 2 and 3. FIG. 2 shows the boat heeled over through an angle theta relative to the vertical as a result of the wind forces on a crosswind or upwind course. These large lateral or sideways forces deriving from the wind force on the sails also give an additional lateral downwind or sideways motion to the boat called leeway as the boat moves horizontally forward across the surface of the water. This leeway angle is represented by the angle gamma of FIG. 3. The leeway angle can be periodically enlarged or diminished due to the cyclical wave motions that vary in opposite horizontal directions from wave crest to wave trough. As a result, the angle of attack of the relative water flow at the keel and rudder can be as high as 70° in a downwind direction at the trough and as low as −20° in an upwind direction at the wave crest. The combination of boat heeling and water flow due to boat leeway motion causes the direction of the water flow past the keel to have a component direction along the span of the keel that is toward the bottom of the keel. This flow component is roughly proportional to the heeling angle. It is during this condition of sailing that the keel and the rudder are most likely to stall due to the higher lateral force load on those members.

The present invention takes advantage of the aforementioned component of flow toward the bottom of the keel when sailing crosswind or upwind to provide the generation of trailing vortices on the sides of the keel or rudder without incurring a large induced drag penalty during downwind or lightwind sailing. By placing a row of vortex generator foils 21 along the keel 18 and the rudder 19 as shown in FIGS. 1 and 5 on each side of the stabilizing members, trailing vortices will be gener-

ated along the surfaces of the stabilizing members to delay stall of the members while sailing under cross or upwind conditions in a heeled over attitude. As mentioned hereinbefore, the vortex generator foils are preferably placed in a nearly fore and aft attitude extending horizontally from the surfaces of the stabilizing members. As also mentioned hereinbefore, the plan shape of the foils is preferably a rounded or delta (triangular) shape to minimize attachment of weeds.

For the purposes of showing a steady state angle of attack at the vortex generators for upwind or crosswind sailing, the effect of the angle of attack due to wave action will be presumed negligible. Referring first to FIG. 10, the keel 18 is depicted as the boat is sailing upwind or crosswind. The fore and aft direction of the boat is represented by the long dimension of the keel 18 and the velocity of the boat, VB is displaced in a downwind direction through the angle gamma as previously described with reference to FIG. 3. As a consequence, a vector diagram may be constructed representing the relative velocity of the water VW past the keel 18 which is equal in magnitude and opposite in direction to the velocity of the boat V_B. The water velocity V_W, hereinafter referred to as V, has two components V cosine gamma parallel to the surface of the keel and V sine gamma perpendicular to the surface of the keel.

Since the boat is also heeling through the angle theta as seen in FIG. 2, reference is made to FIG. 11 to resolve the vector V sine gamma into its components perpendicular to and parallel to the surface of the keel when heeled through the angle theta. The component parallel to the surface of the keel and downward in the span direction on the keel may be seen from the vector diagram of FIG. 11 to be the quantity V sine gamma sine theta. The other component of water flow velocity which determines the water angle of attack relative to the vortex generator foils is the quantity V cosine gamma from FIG. 10, which is parallel to the surface of the keel in the direction of the chord. FIG. 12 shows the vector diagram which describes the angle of attack alpha. It is determined by the components V cosine gamma and V sine gamma sine theta to produce the direction of water flow relative to the vortex generator foils. It may be seen that the tangent of the angle alpha is the quantity V sine gamma sine theta over V cosine gamma. Therefore, alpha equals arc tangent sine gamma sine theta over cosine gamma. Relatively straightforward calculations reveal that if gamma equal 5° and theta equals 20°, then alpha equals 1.7°. However, if gamma equals 10° and theta equals 30°, then alpha equals 9.84°. It may be seen that the higher the leeway and heel angles, the greater the angle of attack of the water at the keel and the greater the benefit created by the vortex generators in reconstituting the boundary layer at the keel surface to thereby improve the L/D ratio as hereinbefore described.

It may be considered desirable to tilt the vortex generators downward slightly toward the bow to increase the angle of attack previously calculated with reference to FIGS. 10, 11 and 12. This will exact some slight penalty during downwind or lightwind sailing conditions, but will enhance the benefits of vortices and delayed stall conditions as hereinbefore described.

The use of the vortex generators 21 may be extended to a number of sailing craft stabilizing members. For example, the hull 17 of FIG. 8 shows the keel 18 having laterally extending winglets 26 attached to the lower edge thereof. The winglets have vortex generators 21 along the upper and under surfaces as shown in FIG. 8. The vortex generator foils delay stall in the winglets in the same manner as hereinbefore described for the keel 18 or the rudder 19.

FIG. 9 shows a sail board 27 resting on the water surface 12 having a sail and mast configuration 28 well known to those in this art. The sail board is shown having a centrally located keel board 29 extending through a box formed in the sail board and having vortex generator foils 21 attached thereto as hereinbefore described for the keel 18 and rudder 19 of FIGS. 1 and 2. It should be noted that for this configuration the box in the sail board for receiving the center board 29 will require lateral openings to allow passage of the vortex generator foils 21 as the center board is inserted and removed. FIG. 9 also shows a skeg 31 positioned near the aft end of the sail board 27. The skeg also shows an array of vortex generators 21 attached thereto in the fashion and for the purposes hereinbefore described.

As described herein the present invention takes advantage of all of the span wise flows relative to sail craft depending stabilizing members and the angles of attack of these flows past the members when the sailing craft is traveling crosswind or upwind or on a broad reach. By placing the array of small spaced low aspect ratio vortex generator foils in a fore and aft direction on the surfaces of the depending members, trailing vortices are generated during boat heeling and leeway travel that mix the free flowing water with the boundary layers on the depending members to delay stall thereof, minimize the loss of horizontal lift on the members, and delay increase in drag due to stall of the members. When the boat is going downwind or in lightwind conditions the flow past the vortex generators is essentially parallel to the axes of the generator foils. The only additional drag loss going downwind is due to the small increase in additional wetted surface area and a small increase in frontal or profile drag. This can be negated by the use of a smaller keel and rudder, for example, made possible by the increase in efficiency resulting from the use of the vortex generators.

The invention envisions the spaced array of vortex generators 21 being placed in parallel array at an angle relative to the leading and trailing edges of the strip 22. This orientation of the vortex generator array on the strip is to accommodate location of the strip at a constant percentage of chord on a keel, for example, with a positive rake aft at the leading edge. It has been found appropriate to locate the array of generator foils at approximately thirty percent of the chord distance from the front edge of the stabilizing member.

Although the best mode contemplated for carrying out the present invention has been herein shown and described, it will be apparent that modification and variation may be made without departing from what is regarded to be the subject matter of the invention.

What is claimed is:

1. A sailboat keel having opposing surfaces with a vertical span and a fore and aft extending chord, comprising a plurality of spaced vortex generators aligned in a row in the direction of the span and extending laterally from the keel and aligned substantially with the chord, wherein said plurality of vortex generators comprise a continuous strip adapted for attachment to the surface of the keel, and a plurality of integral vortex generators extending therefrom.

2. A sailboat keel as in claim 1 wherein said continuous strip comprises a concave surface adapted for at-

tachment adjacent the surface of the keel and a convex opposing side from which said vortex generators extend, whereby said strip has a leading edge faired into the keel.

3. A depending stabilizing member having a span extending from the underside of a sail equipped vessel adapted for wind driven movement across a water surface, comprising an array of spaced vortex generators attached to and extending laterally from the stabilizing member along at least a portion of the span of the stabilizing member, wherein said spaced vortex generators comprise a strip extending in the span direction, and a plurality of integral foils spaced therealong and extending therefrom.

4. A depending stabilizing member as in claim 3 wherein said strip comprises a concave under surface and a convex upper surface from which said foils extend.

5. Apparatus for inducing vortices in a flowing fluid comprising a strip for fastening to a keel and rudder of a sail equipped vessel, opposing edges on said strip, a concave surface on one side of said strip, a convex surface on the opposing side of said strip adapted to lie adjacent the keel and rudder, said one and opposing sides sharply intersecting at least one edge of said strip, and a plurality of integral vortex generators extending between said edges.

6. Apparatus as in claim 5 wherein said plurality vortex generators comprises an array of substantially parallel foils.

7. Apparatus as in claim 5 wherein said vortex generators comprise low aspect ratio foils.

8. Apparatus as in claim 5 wherein said plurality of vortex generators comprises foils having a rounded edge proximate said sharply intersecting side of said strip and a tapered trailing edge.

9. Apparatus for fastening to a rudder and a keel on a sailboat for inducing vortices in an incompressible fluid flow, comprising a strip having a forward edge and a trailing edge, an upper surface and an under surface on said strip, said under surface being shaped to lie against the rudder and the keel, said upper and under surfaces intersecting at an acute angle at said forward edge, and a plurality of vortex generating foils extending from said upper surface and between said forward and trailing edges.

10. Apparatus as in claim 9 wherein said under surface comprises a concave surface and said upper surface comprises a convex surface.

11. Apparatus as in claim 9 comprising an acute angle intersection between said upper and under surfaces, at said trailing edge.

12. Apparatus as in claim 9 wherein said plurality of vortex generating foils comprises an array of, substantially parallel foils.

13. Apparatus as in claim 9 wherein said plurality of vortex generating foils comprises a plurality of low aspect ratio foils.

14. Apparatus as in claim 9 wherein said foils comprise plate-like vortex generators, and rounded leading edges proximate to said strip forward edge.

15. Apparatus as in claim 5 wherein said opposing edges are feathered to a sharp configuration.

16. Apparatus as in claim 9 wherein said forward edge and trailing edge are feathered to a sharp configuration.

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